# Editorial Preface

## *From the Desk of Managing Editor...*

It may be difficult to imagine that almost half a century ago we used computers far less sophisticated than current home desktop computers to put a man on the moon. In that 50 year span, the field of computer science has exploded.

Computer science has opened new avenues for thought and experimentation. What began as a way to simplify the calculation process has given birth to technology once only imagined by the human mind. The ability to communicate and share ideas even though collaborators are half a world away and exploration of not just the stars above but the internal workings of the human genome are some of the ways that this field has moved at an exponential pace.

At the International Journal of Advanced Computer Science and Applications it is our mission to provide an outlet for quality research. We want to promote universal access and opportunities for the international scientific community to share and disseminate scientific and technical information.

We believe in spreading knowledge of computer science and its applications to all classes of audiences. That is why we deliver up-to-date, authoritative coverage and offer open access of all our articles. Our archives have served as a place to provoke philosophical, theoretical, and empirical ideas from some of the finest minds in the field.

We utilize the talents and experience of editor and reviewers working at Universities and Institutions from around the world. We would like to express our gratitude to all authors, whose research results have been published in our journal, as well as our referees for their in-depth evaluations. Our high standards are maintained through a double blind review process.

We hope that this edition of IJACSA inspires and entices you to submit your own contributions in upcoming issues. Thank you for sharing wisdom.

**Thank you for Sharing Wisdom!**

# Editorial Board

# CONTENTS

(v)

(viii)

(x)

# Human Coach Technology Reactance Factors and their Influence on End-Users' Acceptance of e-Health Applications

Sarah Janböcke[1], Toshimi Ogawa[2], Johanna Langendorf[3], Koki Kobayashi[4], Ryan Browne[5],
Rainer Wieching[6], Yasuyuki Taki[7]

Tohoku University, Smart Aging Research Center Sendai, Japan[1, 2, 3, 4, 5, 7]
University of Siegen, Business Informatics and New Media Siegen, Germany[6]

*Abstract*—**Project e-VITA is a joined research force from Europe and Japan that examines various cutting-edge e-health applications for older adult care. Those specific users do not necessarily feel technology savvy or secure enough to open up for innovative home tech systems. Thus, it is essential to provide the support that is virtual and human beside each other. Human coaches will provide this support to fulfill this role as a mediator between the technological system and the end-user. Reactance towards the system from the mediator's role could lead to the system's failure with the end user, thus failing the development. The effect of technology reactance in the integration process of a technological system can be the decisive factor in evaluating the success and failure of a technological system. We used part-standardized, problem-centered interviews to understand the human coaches' challenges. The sample included people who act as the mediator role between the user and the technological system in the test application in the study centers. The interviews focused on experienced or imagined hurdles in the communication process with the user and the mediator role as well as the later relationship dynamic between the mediator, end-user, and technological system. The described technological challenges during the testing phase led the human coaches to responsibility, diffusion and uncertainty within their role. Furthermore, they led to a feeling of not fulfilling role expectations, which in the long term could indicate missing self-efficacy for the human coaches. We describe possible solutions mentioned by the interviewees and deepen the understanding of decisive factors for sustainable system integration for e-health applications.**

*Keywords—Technology acceptance; technology reactance; human-machine-interface; technology mediator; technology leverage; human coach, digital health; e-health; virtual coach; active aging, healthy aging; healthcare information technology introduction*

## I. Introduction

### A. Project e-VITA

Under the EU Horizon 2020 program, as well as MIC funding regarding the Japanese Society 5.0 movement, project e-VITA, a Virtual Coach for Smart Aging, forms a research group that aims at conducting knowledge about new technologies and methods to help an aging society deal with specific problems of their older people. The team of sociological, medical, and technological experts joined in one research team spread all over Europe, and Japan aims at developing an innovative coaching system focused on the needs of older autonomous living adults, i.e., a virtual coaching system that can provide personalized recommendations and everyday help to improve older adults' life quality.

### B. The Human Coach in Project e-VITA

e-VITA is aimed at older adults that not necessarily feel technology savvy or secure enough to open for innovative home tech systems. It is thus essential to provide the support that is virtual and human. At least one human coach will provide this support as a mediator between the technological system and the end-user. As a first step, each study center will recruit human coaches to fulfill this critical role. Project e-VITA has various test centers in Japan, Italy, France, and Germany to conduct a human trial such as feasibility studies and proof of concept studies to evaluate the developed virtual coaching system. The main tasks of the human coach will be as follows:

- Teaching end-users about the e-VITA virtual coach (usage, maintenance, support). If needed, end-users will be trained and supported by a team of researchers daily during the study.

- Regular phone calls between the human coach and end-user to answer questions and provide needed support, e.g., explain the appropriate use of the virtual coach.

- Organize real personal meetings of users once a week in the local community.

- Ensuring the security and safety of users, e.g., checking temperature to avoid overheating, safely placing the technical device in the home environment.

- Mentoring, creating awareness, and encouraging behavioral change, encouraging during the intervention.

- Reporting users' requirements, questions, and feedback to the developers to steadily improve the system.

### C. Problem

In the first step within the e-VITA study, the human coaches will be primarily employees or volunteers with a particular affinity for technology and an advanced training status due to their particular relation to the project. In the

expected application of the final concept in the actual field, the human coaches accompanying the technology integration will be employees of care institutions, care services, social associations, and/or family members and local community volunteers. The effect of technology reactance in the integration process of a technological system should not be neglected because it can be a decisive factor in evaluating the success and failure of the technological system used [20]. The final human coaches will act as a kind of 'salesperson' for the system, thus mediating between the human end-user and the technological system. Reactance towards the system from the mediator's role could lead to the system's failure with the end user, thus failing the development [17]. Potential hurdles and reactance factors [25] from the role of the human coach will be explored in more detail in this study.

### D. Contribution

Even though the participants of this study within project e-VITA might possess a fundamental technological affinity, they will be competent enough to deliver valuable information regarding the potential challenges a later human coach will face and, thus, possible technology reactance factors. As mentioned above, technology reactance factors from human coaches in their mediator role will influence the later successful technology integration in the field and following should be considered during the design phase for the technological system. Thus, this study aims at exploring the following three research questions:

- Which technology reactance factors can we find in the role setting of the human coaches?

- How do these factors influence the later end-user relationship towards the installed technology in private home settings?

- Which prospect aspects can overcome reactance tendencies, and which human coach motivating factors play essential roles?

### II. THEORETICAL BACKGROUND AND RELATED WORKS

Advancing Information and Communication Technology (ICT) in healthcare can revolutionize delivering healthcare. From easy access to medical records to the ability to consult virtually with specialists, ICT has the power to improve the patient experience significantly. For providers, ICT can help improve patient outcomes, reduce costs, and increase efficiency. With access to Electronic Health Records (EHRs), providers can quickly access critical patient data, such as medical history and insurance coverage, without waiting for paperwork to be completed. This leads to more accurate diagnoses and faster treatment.

Additionally, ICT can allow providers to communicate quickly with other healthcare professionals, collaborate on patient care, and refer patients to specialists when needed. Moreover, ICT, installed in older people's homes, can ensure longer independent living situations for older people, especially in countries with vast demographic challenges and/ or labor shortages in elderly care. In short, ICT, as developed in project e-VITA, can revolutionize healthcare, providing older people with better access to care and providers with

more efficient ways of providing it. The following section describes the theoretical backgrounds of these interrelations as a foundation for this study.

### A. The e-Health Ecosystem in General

The healthcare sector is of paramount societal significance, and Information System researchers have long studied it empirically. The e-health ecosystems are emerging as an effective way to deliver healthcare services to older people cost-efficiently. These ecosystems are comprised of a network of entities - including healthcare providers, tech vendors, and other stakeholders - that facilitate the exchange of data and the provision of health services. This can revolutionize healthcare and open new possibilities for providers and older people [7, 12].

The development of e-health ecosystems is driven by the need for healthcare providers to access/ share data quickly and securely and the demand for cost-effective health services. As such, e-health ecosystems comprise various components, including electronic health records (EHRs), patient portals, health information exchanges (HIEs), telemedicine tools, and other technologies. By leveraging these components, healthcare providers can access and share data in real time, reducing administrative costs and providing better patient care access [1].

The e-health ecosystems offer numerous benefits for older people. For example, by providing access to patient or client portals, older people can access their medical records and communicate with their healthcare providers more easily. Furthermore, e-health ecosystems can enable the delivery of care through virtual coaching alongside the personnel in the form of human coaches. However, those technical systems present themselves as another stakeholder in the whole ecosystem, which also comes with several barriers and facilitators [25]. Schreiweis et al. define a list such as limited exposure/knowledge of e-health (e.g., poor digital health literacy), lack of necessary devices, and problems with financing e-health solutions as the top three barriers; as well as facilitating factors such as the involvement of all relevant stakeholders, integration into the overall care, and ease of use [3]. Stephanie and Sharma discuss the critical elements of digital health, including the emergence of digital health ecosystems, formulating a vocabulary of research and sensitizing concepts, and design issues and challenges in creating a viable patient-centric e-health ecosystem. They emphasize the potential of digital health innovations such as evidence-based data analytics, artificial intelligence, Internet-of-Things in remote monitoring and diagnostics, and blockchains for secure, compliant, transparent data management [7]. All authors find common ground in describing the importance of carefully integrating knowledge about the systemic complexity of e-health ecosystems, especially about the formal and informal caregivers as direct contacts to the end-users when integrating technological artifacts for care purposes [8].

### B. Technology Reactance and the use of e-Health Applications

Technology reactance is an important concept to consider when developing and implementing e-health solutions.

Especially the above-mentioned complex ecosystems introduce a variety of critical points with diverse stakeholders in which technology reactance might lead to tech-system-failure [11]. This refers to people's psychological resistance to using technology, particularly when they feel it is being imposed upon them. This can be due to various reasons, such as feeling overwhelmed by the amount of technology available, feeling that technology is intrusive, or feeling that technology is not necessary to reach a desired outcome [20,16]. Technology reactance can potentially hinder the adoption and utilization of e-health solutions. To reduce the likelihood of this happening, developers and promoters of e-health solutions should strive to create user-friendly, intuitive, and reliable solutions that offer clear benefits to their stakeholders. The goal for many years has been to implement health information technology (HIT) for its apparent advantages; however, a significant obstacle to overcome is user resistance. Healthcare professionals should be provided with proper training and support. Attention should be paid to user needs and psychological concerns to create an environment of acceptance and understanding by using Psychological Reactance Theory (PRT) [18]. The psychological reactance theory assumes that people's behaviors are motivated by the desire to protect their "freedom" to carry out a particular behavior in a particular context [13]. The introduction of technology is generally accompanied by new processes demanding the change of (work) routines and task dependencies between employees/people. These processes can potentially cause power imbalances that may lead to perceived helplessness. According to the PRT, resistance is a result of reactance. It is defined as the response to losing freedom [18]. Svioja et al. point out the importance of carefully designed UX in complex systems, especially in safety-critical domains, to overcome stakeholders' possible reactance or resistance tendencies [23]. Subhasisch et al. present a study along the technology acceptance model (TAM) in which they prove that perceived ease of use positively impacts a system's perceived usefulness [4].

Additionally, perceived usefulness and prior use of the system significantly impact the actual use of the system in the end [4]. Parker et al. describe, in general, how work-technologies influence employees such as caretakers. The most publicized risk is the erosion of the need for human workers. Rather than solely speculating about which jobs will vanish, research should address the urgent and prevalent matter of how tasks might best be shared between humans and machines and the consequences of different choices in this respect. It is essential to consider design issues to come to grips with the potential effects of digital technologies and associated changes and to help steer technological development toward desired care futures [19]. Ultimately, technology reactance can significantly impact the success of e-health solutions. By understanding the potential for technology reactance and taking appropriate steps to address it, developers and promoters can help ensure that their intended audiences adopt and utilize their e-health solutions [2,15].

### C. Sustainability Factors in Technology Development

The traditional approach to automation design has focused on optimizing operational efficiency and safety by minimizing human involvement and making systems easier to use for the operator. However, this approach is often met with a lack of acceptance, more severe failures, and an erosion of the sense of purpose that comes with meaningful paid or voluntary work [14]. To address this, more recent theories such as Experience Design, Positive Design, and Design for Well-being propose that technology should be crafted to actively contribute to meaningful, fulfilling work [5,9,10]. Therefore, to place well-being at the center of design efforts, autonomous systems must be created to support meaningful practices. A strong correlation exists between meaningful practices and situational commitment, creativity, and well-being. However, the connection between meaningful practices and technological artifacts is not yet fully understood, especially in work contexts. Smids et al. identify various frameworks that comprise meaningful work, such as pursuing a purpose, social relationships, self-development, self-esteem, exercising skills, and feeling autonomous [25]. Therefore, the design of autonomous systems should consider fulfilling human social needs and ensure sustainable usage based on users' and stakeholders' well-being [21, 22].

### III. Methodological Approach

### A. Interviews and Sample

We used part-standardized, problem-centered interviews [24] to interview the human coaches currently involved in the study at the four test centers (Japan, Germany, France, and Italy). The sample included people who act as the mediator between the user/ older person and the technological system in the test application in our study centers. The part standardized interview focused primarily on experienced or imagined hurdles in the communication process with the user and the mediator role; furthermore, the effects on the mediator and the later relationship dynamic between the mediator, end-user, and technological system. The interviews were conducted in English and German in the EU and Japanese in Japan using Zoom for the meeting and the recording. Two interviewers conducted the interviews. The interviewees were between 21 and 82 years old, with an average age of 49,2 years. We interviewed five persons in Japan, one in Italy, two in France, and two in Germany. The interview length was between sixty and ninety-eight minutes. The interviewees cover a wide range of job expertise shown in Table I. Also shown in Table I are references to the interviewees' role in the test centers, their experience in elderly care, and their self-assessed technology competence. We do not name the interviewees' countries in the table to ensure anonymity.

TABLE II.    INTERVIEW DETAILS

| Age | Job Expertise | Role test entre | Expertise Elderly care | Technology competence |
|---|---|---|---|---|
| 82 | Bank Manager, now civil servant and mediator/ judge | "My role is to listen carefully to the users and be a dedicated listener. I also understood that if they had any problems, I would give them advice." | "When I was a community welfare volunteer, I was also an officer of the local social welfare council, so I had opportunities to listen to the elderly people at their gatherings and so on. When I was a community welfare volunteer, I also visited elderly people who lived alone, so I had opportunities to talk to them." | "I'm not familiar with technology at all. I'd say I'm a three at best." |
| 70 | Project Manager IT, now Freelance same field | "The role of the coach about this project is to first understand the purpose of the project and then to communicate the actual theme of the robot, how easy it is for the user to use, and how to make the robot do what it is supposed to do, and then to help the user to do it." | "I started going to the neighborhood association the year before last, so we are almost the same age. Also, the members of the Go club are almost older than me. The people in the club are so into Go that the members of the club are more of a hobby, and they play against each other on the spot. We play a game about once a week. Those people look forward to playing games, so if anything, I started after 60." | "I've been working with computers all my life, so I don't like to be asked about the level of IT technology involved in networking and things like that when I say with confidence, but I'm between 5 and 10. So then, I'll say 7." |
| 69 | Sales employee for IT | "My job is to guide the assistant robot and help the | "There are so many. There are only elderly people…. | "I'm a ten on the concepts and a 3 or 2 on the |
| | | user." | One is a non-profit organization, one for …. and then another one as a civic contribution, and the third one is the delivery of meals for the elderly and disabled. I am in contact with them through these three. The other thing that I do is with them." | technical aspects of contents. The technical stuff, the details, not at all." |
| 63 | Accounting employee | "I think it is about eliminating the anxiety of users, being close users, and enjoying (the experience) with them." | "My mother is 94 years old, so I also meet people who are close to her. But, just a while ago, not too long ago, people used to come over for tea and chat. Now they have moved away to live with their children… My social interaction is about visiting daycare service…" | "Because I do not know how savvy is 10 (points). About the basic only. Maybe 2 or 3. 2.5." |
| 71 | Call-center employee for mobile phone business, now social activities for the community | "After all, coaching means (to be) fairly well versed in coaching content and able to tell it simply (to users); I think those things are important." | "I participate in my local residents association's salon once a month and I also help the local comprehensive center once a month as long as time permits. Because of those (activity), (I have some interaction with the elderly) to some extent." | "I think (I am) already close to zero." |
| 30 | Psychologist | "I am mainly involved in user recruitment, interviews, and test | | "Maybe nine?" |

| # | Role | | | |
|---|---|---|---|---|
| | | administration." | "I work with senior people, senior with older people, and often with people with dementia or Alzheimer's. And um my, I also work like a psychologist, e-Vita. So outside, e-Vita and I yes, I work with these kinds of people. I do cognitive stimulation or cognitive rehabilitation." | |
| 24 | Research Engineer | "My role is to first create a user guide. And after implementing all the technology in the home of the older person of the participants and to answer their questions when we are in their home." | "I think because I started to work with Senior when I am when I was in a master's degree. So four years old, I think I work with them. In contact." "I had contact in an internship and after my first job as a researcher also." | "I think I'm eight because I like technology, but I'm not a developer, so or gamer, or so like that. So I use them, but I use all the technology like to see what is possible to do, but I'm not touching technical system or like that and it's not my job." |
| 21 | Engineer | "I am currently helping in that project, just like a human coach would do. Calling participants and going to participants' houses to see what's going on." | "Not really. I have done a little project from my engineering, from my engineering formation, which was a sort of remote control for the TV, which was used by the seniors, which were they were doing just like this." | "I really like technology. I'm a bit familiar with them, with it. And I would like to say nine, I think. Nine is great." |
| 28 | Project Manager in Social | "My task as a human coach was, on the one | "(You were already a physiotherapist | "9… Well, I don't understand, |

| # | Role | | | |
|---|---|---|---|---|
| | Science | hand, to install the devices, to introduce them to the devices, and to record the feedback from the users. And when there are technical difficulties, we go to the users and see what's going on and how we can solve it." | in training. Did you then also often deal with senior citizens? Probably also in this context. But-) "Yes mostly actually." | of course not, the complete complexity behind the device, but I can familiarize myself with the practical processes relatively easily and get it down to the chain quickly, quickly. So I can quickly acquire new technologies and new technical knowledge. " |
| 32 | Student Medical and Health Science and Caretaker in part-time | "I'm writing my bachelor's thesis about the study, and then the project manager asked me or asked me if I wouldn't like to take on a role as a human coach." | "So, starting at home with my friend and with his grandmother in his grandmother's house, he has dementia. I also take care of them privately. Then I worked in a nursing home before. Many years. I've always had very close contact with the residents, so there was also an amicable, family atmosphere." | "It all depends on whom you're comparing yourself to. Because I have programming experience, but I'm not exactly a programming expert, and I wouldn't say that at all. Let's say if I compare myself to people who study computer science, I would say a seven." |

## B. Analysis Process

After transcribing the interviews, they were coded for anonymization. According to the different nationalities of the participants, corresponding abbreviations were distinguished to assign them later to possible inductive categories like cultural differences or demographic comparisons. The anonymized texts were then openly coded with the help of four research questions:

- Which technical reactance factors can be found in the role setting of the human coaches?

- How do these factors influence the subsequent relationship of end-users to the installed technology in the home environment?

- Which aspects can overcome reactance tendencies, and which motivating factors of the human coach play an essential role?

- What important information does the interviewee provide concerning their role as an intermediary?

The first category summarizes all statements about the technological reactance factors of the human coach, including the components of their occurrence. In the second group, all quotes were collected on the relationship dynamics between the human coach, end user, and technology. Category 3 dealt with the solution ideas to potential or actual problems, and the last category contained information about how the respondents felt in their mediator role and how they would define it.

The recorded citations were sorted in a table. The individual codes were then analyzed to identify similarities or abnormalities. These were carried out separately by two researchers, whose results were then summarized and processed. In addition, this study explored general knowledge and cultural or demographic characteristics, which we examined as inductive and open-ended.

Based on the collected findings, theories were then formed, and connections developed to filter out the influence of intermediaries on the acceptance of technology and to be able to specify this intermediary role.

### C. Validity Threats and Limitations

Following Engelhardt [6], we can summarize that the interview method was very well suited to finding the needed background information and personal attitudes for this sub-study. The procedure made it possible to ask in-depth questions about certain statements. This ensured that the interviewee was understood correctly and underlying attitudes could be found. This understanding was the basis for further analysis to correctly process the interviewees' statements and not allow personal interpretations to flow in [24]. However, the exact procedure during the interview might differ from the interviewers. One limitation was that different people conducted the interviews due to the language barrier. Each interviewer might have had their interview style, which may have influenced the statements made by the interviewees or even led to certain aspects not being addressed at all or in sufficient depth. In addition, the different cultures of the interviewers and the interviewees could have influenced how openly specific topics were discussed or how vehemently questions were asked about problems of understanding. People of a wide range of ages were interviewed for this study. So, we cannot entirely rule out that questions were understood differently; therefore, comparability might not be entirely given. Probably the most significant limitation of the study was the different languages used. The interviewees gave the interview in Japanese as a native language, English as a non-native language, or German as a native language. Translations were, therefore, necessary for the analysis process. As a result, quotations could have been falsified or statements modified within the translation process, even if a professional translation service proceeded. However, since we conducted the data and proceeded with the analysis under the close supervision of the leading researcher, who also coached the

executing researchers beforehand, we eliminated validity threats as best as possible for this international and complex sub-study.

### IV. RESULTS

#### A. Category 1: Human Coach Technological Reactance Factors

During the analysis process of the first category, we were led by the question of which aspects the interviewees reported about specific use situations and self-responsiveness to the tested technologies. Furthermore, when and where those aspects arose, and which psychological content-wise link can we draw from the given statements?

All those surveyed named the fact that fluent conversations were not possible as probably the most considerable criticism of the tested systems. The devices had limited topics of conversation and had difficulty understanding what was being said, leading to frustration among the seniors. Some seniors were disappointed by how "little" the devices could do. Some of them started the tests with high expectations and were then disappointed. For them, using it was sometimes more severe work than fun.

In general, the interviewees found that the system for communicating with a robot was still in development, making conversation difficult at the beginning due to its response. It was found that the conversation was not going smoothly due to changes in the example conversation in the manual, and it was suggested that the conversation should be more cumulative to improve this. It was mentioned that while care should be taken not to exceed certain limits regarding technology, it should not be intrusive regarding privacy. In addition, it was criticized that the voice would sound metallic and invite only limited conversations. There was sometimes a lack of feedback from the system, for example, when it started processing for a search, but it needed some time. It was repeatedly criticized as unnatural that one had to press a button to start a call. This was also difficult for some seniors to understand. However, it was positively emphasized that the robot would turn its head in the direction of the voice. This made the conversation more natural for the seniors. The simultaneous textual reproduction of what was said on the Gatebox gave seniors certainty that the device understood what was said correctly.

The limited functions were another disappointment for the seniors. They could only perform a few, often simple actions with the devices and needed a smartphone for them. This would make it easier for them only to use the standard apps, so the e-VITA devices hardly offer them any added value. Some seniors also had difficulties using Telegram because they were unfamiliar with this app or Messenger in general and thus had to learn several new technologies at once. According to some seniors, these limitations in connection with the poorly functioning voice control made the devices either just a kind of entertainment without added value or useless. During the experimental period, the users noted that it was a toned-down version of the commercial version, not providing the expected response or reaction. The user hoped that the robot would suggest activities such as going outside

and showing empathy when the user was crying. They raised concerns about how the robot would be used and suggested positioning it as a pet or healing tool. One interviewee expressed surprise at how well the users responded to the robots and found them helpful in relieving loneliness. The interviewee also wonders if the robots could be used to help people with dementia and if those with more difficulty could operate them. The interviewees also reflect on their experience with technology, feeling that their world has opened and expanded. They noted that the older adults they had accompanied were apprehensive about robots but would accept basic conversations about everyday topics. They observed that many of the older adults did not understand how to use the technology or that it was usual for the robot to get hot, which scared them.

Some respondents received feedback from seniors during testing that they felt the systems were inappropriate, which concerned, for example, the design and the character, but also the structure of the functionalities. Some of these were not self-explanatory enough, so they needed help to use them.

Other problems that arose were, for example, that the seniors in small apartments had too little space for the devices. In addition, some voiced concerns about the power consumption and the associated costs or the overheating of the devices. Poor WLAN also sometimes posed a hurdle for use. One of the respondents expressed criticism of the further plans in the e-VITA project, that they were not specific enough about data use. For example, the interviewee mentioned that information should be passed on to health insurance companies through the devices in the future. However, this passing on could also be to the detriment of the senior citizen if he/she does not maintain a healthy lifestyle and the health insurance company refuses to provide benefits.

Overall, it can be said that the tested technologies are not yet failsafe enough for the seniors; the voice control needed optimization, and more possible actions tailored to seniors would have to be implemented so that the systems tested in e-VITA would unite the seniors have actually added value and can therefore be used sustainably.

The mentioned technological challenges during the testing phase led the human coaches to responsibility diffusion and uncertainty within their role. Since we followed a relatively open interview style, those interconnections were steadily mentioned during the recording phase without specific questioning. The technological challenges led to a feeling of not fulfilling their role expectations or job descriptions entirely, which in the long term could indicate missing self-efficacy for the human coaches. This aspect might lead to a problem when integrating a new eHealth system with a sustainability focus.

We will now analyze the mentioned psychological challenges with the following analysis parts.

### B. Category 2: What Relationship Dynamics can we see in the usage Triangle of Human Coach, end user, and Technology?

Both caregivers and seniors in the study expressed disappointment at how little current devices could do. They each had higher expectations and were disappointed. For example, it was criticized that the systems did not respond to the senior as an individual but remained very impersonal or gave generic answers. Overall, the conversations should be more natural and focus more on the senior instead of simple question-and-answer exchanges. There was also criticism that too many individual, non-networked applications should be tried simultaneously. As a result, and due to the limited functionality and personalization, some of these were not tailored to the announced project goal, namely, to increase senior citizens' well-being and advise them on health and social issues.

Several respondents said it was positive that there was a lively exchange between senior citizens, intermediaries, and developers. This allowed them to act as facilitators, giving feedback and getting answers from the developers about how something worked or why it worked a certain way. This social inclusion through involvement in the development of the system that was not initially part of the study phase might be an essential indicator for the later integration of the system and its further development.

The participating older adults often saw the robot as a kind of pet or assistant that reminded them of medication, for example, but also encouraged them to talk and interact. To do this, however, the system must also respond to the character of the individual seniors. For example, it must act if the senior using the device suffers from dementia and needs different treatment than a senior without dementia.

Several intermediaries stated that they considered it crucial to also convey to the seniors what the robot can and cannot do, to deal with their sometimes very high expectations. Some older adults were disappointed when something did not work and reacted angrily. The mediators found this critical since they wanted the systems to enrich the lives of older people. They were convinced that long-term, sustainable use would only come if seniors also wanted to use the technology and could try it out over a more extended period to experience the added value for their lives. This approach to the aspects of enrichment and the limits of technology was described as an essential task of a mediator. However, the seniors were perceived as curious about the technology and interested in interacting with the devices. There were a few exceptions, where some respondents felt that the seniors were only participating in the project to please them and were, therefore, less motivated to try the devices.

The interviewees described as an essential basis for the cooperation that a basic trust between the senior, mediator, and developer is necessary. It is also important not to patronize the seniors but to let them set up the devices themselves if they feel up to it or to accept if they do not want to use specific devices. Several mediators empathized with the seniors, enjoyed the cooperation, and appreciated mutual respect.

### C. Category 3: Which Solution Ideas are Offered by the Respondents?

In conclusion, it is vital to understand the needs of older people individually and in more depth, such as what they need

and want, so it is necessary to collect data more widely, the interviewees summarized. It is essential to make the operations as simple as possible and to explain the vision in a way that is easy to understand for older people. It is crucial to foster mutual understanding between the older user and the robot and create a sense of control for the target group. Finally, it is essential to make sure that the technology is suitable for the needs of older people and that it is entertaining.

To develop technology that is tailored to seniors, the data collection in advance should focus more on their needs and perceive the seniors as individuals, according to the respondents. Some said there is more than one group of seniors, and one needs to identify which groups of seniors have which needs and, therefore, would benefit from a particular technology. In addition, some intermediaries expressed that they would instead test several small functionalities one at a time to be sensitive to feedback and to be able to develop technology in a more tailor-made way. Also, before handing out the technology to the seniors, ensure the systems will improve their lives, not complicate them. They suggested that vocal interaction was better than other forms of interaction and that medical reminders would be beneficial. They also suggested that physical activity advice was essential and that robots should have an emergency button. Finally, they noted that it was unclear whether robots should be rented or bought and that some older adults preferred to rent them monthly, while others preferred to buy them outright.

Respondents would like more time to prepare and try the devices before bringing them to the seniors. In this way, they could familiarize themselves more intensively and, for example, get the missing power adapter or better prepare the presentation to the seniors. The level of this presentation should also be as low-threshold as possible since many technologies are new to seniors, so they must learn them from the very beginning. In addition, the intermediaries wanted to receive a kind of operating manual at the beginning to get a common understanding of the project and the devices.

According to those surveyed, senior citizens and caregivers should not only be provided with operating instructions and explanatory videos, but continuous support from caregivers. In this way, the latter would have the opportunity to explain or practice things several times, thereby optimally supporting the seniors in learning to operate systems. It is also essential to respond to the seniors' level of knowledge and adapt the explanations accordingly.

When introducing the devices, the vision or goal of the development should also be addressed to involve the seniors in the project. In addition, it would have to be communicated that the technology was still in development. In this way, the seniors can be better involved. According to the intermediaries, it is also imperative that nothing is hidden from the user. They must be told openly what the robot is doing or why, i.e., if data is recorded and how it is used. Even if one feels that the seniors do not understand the topic of data protection, for example, everything should still be explained to them openly.

According to those surveyed, the devices themselves should not be too complicated to use and should make the user happy. This requires a specific range of functions since the seniors were disappointed with how little the devices could do. The seniors must be able to switch off the systems at any time and thus control them. Voice interaction must work better if one wants to use social robots, and conversations must be set up and conducted from the user's point of view. The interaction could also be loosened up with jokes, for example, and the seniors should be able to choose between different voices or ways of interacting, such as severe or funny.

According to the interviewees, there should be a direct contact person for technical problems, and a better complaints management system should generally be introduced. This would allow the problems of older people to be addressed more quickly and flexibly. The intermediaries themselves could seldom solve technical problems on their own; they could only pass them on. This led to frustration for both agents and seniors. In addition, the exchange timing should be based more on the everyday life of the seniors instead of being geared toward the developers or mediators.

We argue that considering the solutions given by the human coaches themselves when designing the technological e-health system will help to develop a more sustainable solution.

*D. Category 4: What Important Information does the Interviewee Provide about their Role as Intermediary?*

All respondents agreed they would have needed more time and opportunities to prepare in advance. The interviewees suggest that they could have had more success if they had taken more time to stay with the seniors and explained how the robot works in more detail. They stated that they were often unable to answer senior citizens' questions and therefore felt uncomfortable. They felt that, in this way, they could not meet the needs of the seniors and also did not fulfill their role as mediators. Those surveyed would have liked to have tested the devices more intensively in advance to have more experience using them. One intermediary even reported that the senior knew more about the device and technology than he did, which made him uncomfortable in his role. A technical meeting beforehand, in which the devices and how they work, could have helped them with these problems. In addition, they would have liked to have had a more extensive range of operating instructions or additional in-depth information to better prepare for their role. To do this, the human coach should prepare in advance, including getting familiar with the project, the robot, and the user. The coach should also be aware of the user's age, background, and technical savvy to be able to communicate effectively and teach them. The interviewees felt the university was unprepared, lacked a manual and information, and did not complain. They believe the goal is to eliminate users' anxiety, be close to them, and enjoy the experience together. Technical knowledge is only at a basic level but the basis for building trust in the relationship triangle. The interviewees feel it is better to make users feel interested and have fun with the technology instead of making them feel like they cannot use it.

In addition to providing support with problems and answering seniors' questions, respondents also saw it as part of their role to be there for the seniors, to address their fears, and to build a relationship with them in general. They felt that listening to the seniors and not making them feel like they were being guinea pigs was essential. They wanted to interest users in the technology and motivate them to use it, but not persuade them. It was also important to them to respect the seniors and treat them as equals. The interviewees' self-conception is that the role of the human coach in this project is to listen carefully to the user and provide advice if they have any difficulties. They should be able to explain the project's purpose, how to use the robot and its functions, and how to nurture it. The human coach should also have a good understanding of the technology and hardware involved and can provide clear instructions and explanations. They should also empathize with the user to build a trusting relationship.

When working with the seniors, the mediators wanted to respond to the seniors' level of knowledge to adapt their explanations accordingly. At the same time, it was stated that explaining technologies such as messenger services to seniors unfamiliar with them was challenging.

If they could not answer the seniors' questions, they saw it as their job as mediators to forward them support. However, this sometimes led to frustration because no solution was found due to the long distances, and they could not help the seniors. As a further task, some of those interviewed defined setting up the devices for the senior citizens and picking them up at the end of the project phase. However, one of the facilitators made it very clear that he did not want to feel responsible for programming the robot, installing anything, and making it operational. Another criticized that he felt very uncomfortable going to the seniors with equipment that was not fully working.

In conclusion, human coaches must be outgoing and confident when interacting with people to help them better understand and use technology.

For the future, the wish was expressed to organize an information event before the equipment was set up for the seniors, at which the seniors would be informed about the project goal and what the devices would be like. In addition, some people wished to have more face-to-face meetings with the seniors to provide them with the best possible support and get to know them better. In this way, the intermediaries could first demonstrate the device and then start the explanations, as desired by one of them. There was also a demand that more information should be provided about data collection and processing so that intermediaries can pass on this critical information to older adults.

They also suggest that having a technical meeting with someone experienced with the technology and showing the seniors how the robots work in real life would help them understand how to use the robots better. The problem for the interviewees was that there was not enough time to get used to the devices before the study began. This led to negative feelings and a sense of responsibility as they had to justify any problems that arose. They felt motivated to ensure the study was successful but had to limit their involvement as they were

not a full-time employee. They believed it was essential to be familiar with the devices and technical context to explain while promoting self-efficacy experiences. These discrepancies should be considered for the latter human coaches to enable them for their task and ensure the technological system will be used sustainably.

*E. Cultural Differences and Demographic Aspects*

We could not find any aspects in our data that justify a cultural difference comparison. We could see that depending on the cultural setup for care facilities and care infrastructure, the technical needs of the used technical system differ a lot. However, for examining the role of the human coach, we could not identify cultural specifics that would justify a category on its own within this sub-study. Furthermore, we could not identify specific differences for comparing, e.g., age aspects in perception or role understanding. It was striking that the older respondents often not only report from the perspective of the older adults within the study but also consider their perspectives. In addition to possible functions or possible uses, this also affected the view of the current devices in the study. The younger participants did not have this perspective and remained in a more objective state of the report.

## V. DISCUSSION

*A. Findings*

Based on the interview data, it can be deduced that language interaction was significant to the respondents. They expected fluent conversations and a more comprehensive range of topics to discuss. Some also complained that the robots' voices sounded too technical. We found that the interviewees stated most prominently that the tested technologies had limited functions, poor voice control, and poor design and character. Furthermore, the structure of the functionalities was not self-explanatory enough. For example, respondents would like the system to notify the user when processing an entry or performing a search. The user should therefore be informed about the current system status, including its actions. The ability of the devices to have realistic, profitable conversations, including action explanations, seems to have an important influence on the reactance.

The range of functions also influenced the reactance. The respondents had high expectations of the devices, which were not met. In addition, some felt that the systems were not tailored to them. Therefore, it seems necessary to offer users functions with added value tailored to their needs. The technological challenges led to responsibility diffusion and uncertainty for the human coaches, potentially resulting in a lack of self-efficacy.

Category 2, which introduced the focus of relationship dynamics in the usage triangle of human coach, end user, and technology, indicated that it was felt to be very optimistic that there was a lively exchange between seniors, mediators, and developers. Questions could be answered quickly, and problems or feedback passed on. The mediators found this to be positive since they had a technical contact person and could get help despite the short preparation time and resources. In

this way, an essential trust could also be created as a prerequisite for cooperation. The seniors often viewed the devices as some pet or assistant, so they had certain expectations. These were not always realistic, which could lead to disappointment and frustration. It is, therefore, crucial that the mediators are fully informed about the functions and can also pass this information on to the seniors, right from the start. In combination with a higher level of reliability, the intermediaries could imagine sustainable use. In addition, the mediators would like to be socially included in the development process. Lastly, there seems to be a necessity for essential trust between all involved - mutual respect and appreciation of cooperation. We can thus summarize that for the relationship triangle of technology, user, and human coach; it is vital to consider those possible challenges that might lead to responsibility diffusions mentioned above and false, hindering expectations from all parties.

Category 3, which offered the opportunity to give in participatory ideas from the interviewees, showed us that data collection should be more comprehensive to understand the needs of individual seniors. Intermediaries should test functionalities one at a time and customize technology accordingly. They need to have enough time to prepare for and try out devices to ensure a good user experience. Explanations should be low-threshold and tailored to the individual's knowledge level. The introduction of the devices must also take place at the knowledge level of the seniors; the level must be tailored to them and their understanding of technology. These principles make it possible for the older person to feel in control of the robot and be able to use it without outside help. According to the mediators, this is the only way to achieve sustainable use.

To adapt the introduction for the seniors, the facilitators would need more time and information in advance to prepare optimally and start interacting with the seniors with a feeling of security. In addition, the intermediaries could also help with problems more quickly instead of often going through lengthy detours via the developers.

When setting up the ecosystem, it is thus of essential importance to consider an additional service that might help with upcoming tech challenges.

In Category 4, the interviewees reported in detail about their role as intermediaries. The facilitators agreed they needed more preparation before going to the seniors with the devices. In addition, they would like more time with the seniors to slowly introduce them to the individual devices and to be able to explain their functions in peace.

It would have been essential for their role to feel like a competent contact person for the seniors. This was often not possible for them due to a lack of advanced information and preparation time and, in some cases, the equipment's susceptibility to errors. In the event of problems, the mediators often could not help immediately and had to contact the developers themselves. They said this could have been avoided with better, more intensive preparation and detailed instruction manuals.

In addition to introducing the devices, the facilitators considered the emotional component crucial to their role. They wanted to be able to develop a relationship with the seniors to address their fears and worries and to be able to resolve them. They aimed to meet the older persons on eyelevel and to motivate them to use the device, but not to persuade them.

Summarizing, we can state that respondents wanted more time and opportunities to prepare in advance, as they felt uncomfortable if they could not answer questions from the senior citizens. They also desired to be able to test the devices more extensively before the event and become familiar with the technical context. Furthermore, respondents saw it as part of their role to be there for the seniors, to address their fears, and to build a relationship with them. When setting up the e-health ecosystem, we argue that it is necessary to consider the psychological aspects of the involved human coaches as much as those of the end-users to ensure sustainable technology usage and integration.

*B. Limitations*

A general limitation of qualitative research is a certain degree of subjectivity. The previous experience and working methods of the person carrying out the work can always influence the result. The weighting or interpretation of individual statements may also differ between different researchers. This was at least a little prevented in the present study because two different study participants looked at the results independently and evaluated the citations. The results were then processed together. Nevertheless, a certain degree of subjectivity is difficult to rule out completely.

In the present study, with 10 participants, comparatively few people were interviewed. To make matters worse, they formed a very heterogeneous group. There were several nationalities and an extensive age range represented. In addition, the participant's experience and knowledge about technology and robotics differed significantly. Due to this broad spectrum, whether generalizable results can be derived must be questioned. Technological competence could lead to the participants defining and fulfilling their roles as intermediaries in very different ways.

The unique view of one's role as an intermediary could also have been influenced by how long the respondents had already been employed in the associated e-VITA project and what tasks they had already carried out as part of this activity.

The distribution of nationality and age was very heterogenic. While five Japanese participated in the survey, only two German participants, for example, who were both relatively young, commented. This makes it difficult to compare the individual groups of participants.

Since we interviewed persons currently involved in the study, we cannot entirely ensure that the latter human coaches would present the same assessment as our interviewees. Since we are faced with several open questions regarding the system itself and the surrounding ecosystem, we must consider that those open aspects might influence the relationship dynamics of the triangle of human coach, user, and technological system. For example, we are still not sure about the final legal

aspects. The legal aspects of the system must be clarified: Who will be responsible for its later use and instruction? Furthermore, the target group of the human coaches must be considered: Will they be a diverse target group or a homogenous target group? The community level must also be considered: What part will the community play in supporting or hiring human coaches? Municipalities must determine which of the current ICT instructors will be the final human coaches in the final use of the system. Finally, social services and welfare organizations must consider which services they already offer for tech coaching and if they can be used for the later use of the tech system. To name some aspects that might be relevant for the relationship triangle and the latter assessment of the technology used.

Since we just had access to ten human coaches within this study, we must evaluate the sample as relatively small. However, we discussed in detail and at great length how the human coaches feel about the technological system and its relationship dynamics. We, thus, considered the sample sufficient for a first qualitative approach.

We also expect that conducting data in a group with similar technological savviness or ignorance might influence the results. However, since we could not access this kind of group within the study and concerning the open aspects mentioned above, we consider the results valuable indicators for our study, the development of project e-VITA, and other e-health developments.

*C. Future Studies*

In the future, we see the need to research the differences between different cultures, age groups, and levels of technological savviness to provide an excellent opportunity to explore the potential of future e-health technologies. For example, research into how people from diverse backgrounds interact with technology could reveal ways to bridge the gap between tech-savvy and those who are not. Additionally, research into the potential of human coaches, who are not currently involved in a particular setting, could provide valuable insights into how e-health technology can facilitate learning and growth. Finally, research into the effectiveness of e-health technology in a setting without open aspects and a fixed framework could provide valuable insights into how this specific technology can be used to create a more dynamic learning environment. All of these research opportunities could help us better understand how e-health technology and the ecosystem can be used to benefit people from different backgrounds and provide them with better access to healthy living opportunities at a later stage in life.

REFERENCES

[1] M. A. J. Roubroeks, J. R. C. Ham, and C. J. H. Midden, "The dominant robot: Threatening robots cause psychological reactance, especially when they have incongruent goals," Lect. Notes Comput. Sci. (including Subser. Lect. Notes Artif. Intell. Lect. Notes Bioinformatics), vol. 6137 LNCS, pp. 174–184, 2010, doi: 10.1007/978-3-642-13226-1_18/COVER.

[2] M. N. Ngafeeson and J. A. Manga, "The Nature and Role of Perceived Threats in User Resistance to Healthcare Information Technology: A Psychological Reactance Theory Perspective," https://services.igi-global.com/resolvedoi/resolve.aspx?doi=10.4018/IJHISI.20210701.oa2, vol. 16, no. 3, pp. 21–45, Jan. 1AD, doi: 10.4018/IJHISI.20210701.OA2.

[3] B. Schreiweis, M. Pobiruchin, V. Strotbaum, J. Suleder, M. Wiesner, and B. Bergh, "Barriers and Facilitators to the Implementation of eHealth Services: Systematic Literature Analysis," J. Med. Internet Res., vol. 21, no. 11, Nov. 2019, doi: 10.2196/14197.

[4] K. Karhu, R. Gustafsson, and K. Lyytinen, "Exploiting and defending open digital platforms with boundary resources: Android's five platform forks," Inf. Syst. Res., vol. 29, no. 2, pp. 479–497, 2018, doi: 10.1287/isre.2018.0786.

[5] R. G. Fichman, R. Kohli, and R. Krishnan, "The role of information systems in healthcare: Current research and future trends," Inf. Syst. Res., vol. 22, no. 3, pp. 419–428, 2011, doi: 10.1287/isre.1110.0382.

[6] A. Bahga and V. K. Madisetti, "A cloud-based approach for interoperable electronic health records (EHRs)," IEEE J. Biomed. Heal. Informatics, vol. 17, no. 5, pp. 894–906, 2013, doi: 10.1109/JBHI.2013.2257818.

[7] L. Stephanie and R. S. Sharma, "Digital health eco-systems: An epochal review of practice-oriented research," Int. J. Inf. Manage., vol. 53, Aug. 2020, doi: 10.1016/J.IJINFOMGT.2019.10.017.

[8] A. García-Holgado, S. Marcos-Pablos, and F. J. García-Peñalvo, "A model to define an ehealth technological ecosystem for caregivers," Adv. Intell. Syst. Comput., vol. 932, pp. 422–432, 2019, doi: 10.1007/978-3-030-16187-3_41/COVER.

[9] S. Janböcke and S. Zajitschek, "Anticipation Next: System-Sensitive Technology Development and Integration in Work Contexts," Inf. 2021, Vol. 12, Page 269, vol. 12, no. 7, p. 269, Jun. 2021, doi: 10.3390/INFO12070269.

[10] M. N. Ngafeeson and J. A. Manga, "The Nature and Role of Perceived Threats in User Resistance to Healthcare Information Technology: A Psychological Reactance Theory Perspective," Int. J. Healthc. Inf. Syst. Informatics, vol. 16, no. 3, pp. 21–45, Jan. 2021, doi: 10.4018/IJHISI.20210701.OA2.

[11] E. S. Knowles and J. A. Linn, "Resistance and persuasion," Resist. Persuas., pp. 1–337, Dec. 2003, doi: 10.4324/9781410609816.

[12] P. Savioja, M. Liinasuo, and H. Koskinen, "User experience: does it matter in complex systems?," Cogn. Technol. Work, vol. 16, no. 4, pp. 429–449, Nov. 2014, doi: 10.1007/s10111-013-0271-x.

[13] S. Dasgupta, M. Granger, and N. McGarry, "User acceptance of e-collaboration technology: An extension of the technology acceptance model," Gr. Decis. Negot., vol. 11, no. 2, pp. 87–100, 2002, doi: 10.1023/A:1015221710638.

[14] S. K. Parker, A. Van Den Broeck, and D. Holman, "Work design influences: A synthesis of multilevel factors that affect the design of jobs," Academy of Management Annals. 2017, doi: 10.5465/annals.2014.0054.

[15] A. Bhattacherjee and N. Hikmet, "Physicians' resistance toward healthcare information technology: A theoretical model and empirical test," Eur. J. Inf. Syst., vol. 16, no. 6, pp. 725–737, 2007, doi: 10.1057/PALGRAVE.EJIS.3000717.

[16] C. Lin, I. C. Lin, and J. Roan, "Barriers to physicians' adoption of healthcare information technology: An empirical study on multiple hospitals," J. Med. Syst., vol. 36, no. 3, pp. 1965–1977, Jun. 2012, doi: 10.1007/S10916-011-9656-7.

[17] J. D. Lee and B. D. Seppelt, "Human Factors and Ergonomics in Automation Design," in Handbook of Human Factors and Ergonomics: Fourth Edition, G. Salvendy, Ed. Berlin Heidelberg: Springer Berlin Heidelberg, 2012, pp. 417–436.

[18] P. M. A. Desmet and A. E. Pohlmeyer, "Positive design: An introduction to design for subjective well-being," Int. J. Des., vol. 7, no. 3, pp. 5–19, 2013, Accessed: Mar. 20, 2020. [Online]. Available: http://www.ijdesign.org/index.php/IJDesign/article/view/1666/595.

[19] M. Hassenzahl, "Experience Design: Technology for All the Right Reasons," Synth. Lect. Human-Centered Informatics, vol. 3, no. 1, pp. 1–95, Jan. 2010, doi: 10.2200/s00261ed1v01y201003hci008.

[20] M. Hassenzahl, K. Eckoldt, S. Diefenbach, M. Laschke, E. Lenz, and J. Kim, "Designing moments of meaning and pleasure.," Int. J. Des., vol. 7, no. 3, pp. 21–31, 2013.

[21] J. C. Walliser, E. J. de Visser, E. Wiese, and T. H. Shaw, "Team Structure and Team Building Improve Human–Machine Teaming With Autonomous Agents," J. Cogn. Eng. Decis. Mak., vol. 13, no. 4, pp. 258–278, Dec. 2019, doi:

10.1177/1555343419867563/ASSET/IMAGES/LARGE/10.1177_15553 43419867563-FIG2.JPEG.

[22] S. Sadeghian and M. Hassenzahl, "The 'Artificial' Colleague: Evaluation of Work Satisfaction in Collaboration with Non-human Coworkers," 27th Annu. Conf. Intell. User Interfaces (IUI 22), pp. 27–35, 2022.

[23] M. Schmidt-Grunert, "Sozialarbeitsforschung konkret : problemzentrierte Interviews als qualitative Erhebungsmethode," 2004.

[24] A. Engelhardt, "Objektivität, Reliabilität, Validität | Crashkurs Statistik," Objektivität, Reliabilität, Validität., 2013. https://www.crashkurs-statistik.de/objektivitat-reliabilitat-validitat/ (accessed Feb. 17, 2023).

[25] J. Smids, S. Nyholm, and H. Berkers, "Robots in the Workplace : a Threat to — or Opportunity for — Meaningful Work?," Philos. Technol., pp. 503–522, 2020, doi: https://doi.org/10.1007/s13347-019-00377-4.

# Multispectral Image Analysis using Convolution Neural Networks

Arun D. Kulkarni

Computer Science Department
The University of Texas at Tyler
Tyler, TX 75703, USA

*Abstract*—**Machine learning (ML) techniques are used often to classify pixels in multispectral images. Recently, there is growing interest in using Convolution Neural Networks (CNNs) for classifying multispectral images. CNNs are preferred because of high performance, advances in hardware such as graphical processing units (GPUs), and availability of several CNN architectures. In CNN, units in the first hidden layer view only a small image window and learn low level features. Deeper layers learn more expressive features by combining low level features. In this paper, we propose a novel approach to classify pixels in a multispectral image using deep convolution neural networks (DCNNs). In our approach, each feature vector is mapped to an image. We used the proposed framework to classify two Landsat scenes that are obtained from New Orleans and Juneau, Alaska areas. The suggested approach is compared with the commonly used classifiers such as the Decision Tree (DT), Support Vector Machine (SVM), and Random Forest (RF). The proposed approach has shown the state-of-the-art results.**

*Keywords—Convolution neural networks; machine learning; multispectral images; remote sensing*

## I. INTRODUCTION

Recently there has been a great interest in the research community to adapt CNNs to analyze multispectral images. Machine learning algorithms such as the decision tree (DT), ensemble of decision trees, support vector machine (SVM), Naïve Bayes classifier and fuzzy inference system are used to classify pixels in multispectral images. CNN-based methods have attracted a great deal of attention due to their ability to dig latent representations and features from images. Borisov, et al. [1] in their survey article provided an overview of deep learning methods for tabular data. They point out that CNN models have repeatedly shown excellent performance and have been widely adapted. However, adaptation of CNN models to tabular data remains highly challenging. DCNNs have shown high accuracy in many image classification applications. They are flexible and allow iterative learning. With advances in hardware and availability of graphical processing units (GPUs) deep learning (DL) models can be used in real-life applications. The main drawback of CNN models is that they commonly use gradient decent backpropagation algorithm with Sigmoid activation functions that leads to saturation resulting in slow gradient convergence, which is known as a vanishing gradient problem. To avoid the vanishing gradient problem, CNNs use entropy loss function with rectified linear units (ReLU) in the output layer. Overfitting usually occurs when the dataset is small. To overcome this problem, various regularization techniques such as dropout and bagging are used. CNN models can be trained with large datasets and can classify images with high accuracy. For ML algorithms, data are presented in the table form whereas for CNN input data are presented in the form of images. CNN models generate a feature vector from input images via convolution and pooling layers. The feature vector represents integrated information from various shapes that are present in the input image.

To use available CNN models and take advantage of these models such as high accuracy, we propose a novel approach to convert data in the table form to images. In ML algorithms input data are in table form, where each row in the table represents a feature vector for an entity and columns describe properties. In many fields such as genomics, transcriptomic, spoken words, financial and banking data are in non-image form. A few researchers have proposed techniques to map numeric data in a table form to images [2 - 4].

We propose a method to map a feature vector into an image. The shapes in the mapped image represent features and ratios between the features. The approach was motivated by two factors. The first motivational factor is that band ratios in Landsat images are used for determining soil moisture coefficients and vegetation indices [5], which indicates that feature ratios contain additional information in the sample than features alone. The second motivational factor is that CNN models provide multiple levels of abstraction and generate a feature vector that combine low-level and high-level information of shapes in the image. To validate our framework, we analyzed two Landsat-8 scenes. Landsat-8 OLI provides images with 30-meter resolution in seven spectral bands. Band 1 reflects deeper blue-violet hues and is used in mapping coastal regions. Bands 2, 3, and 4 are visible blue, green, and red are used in land use mapping. Band 5 measures the near infrared (NIR). Bands 6 and 7 cover different slices of the shortwave infrared (SWIR). They are particularly useful for telling wet earth from dry earth, and for geology [6]

We implemented the algorithm to map table data into images using a MATLAB script. In addition, we implemented Alex Net using MATLAB deep learning toolbox. We analyzed two scenes, one from New Orleans, and another from Juneau, Alaska. To classify pixels in the image each pixel is represented by a vector consisting of reflectance values in multiple spectral bands. We extracted training set data by displaying scenes on the monitor and selecting small homogeneous areas that represent distinct categories on the ground. We selected four training areas that represented four

categories for the Alaska scene, and three training areas that represented three categories for the New Orleans scene. We selected reflectance values from spectral bands 2, 3, 4, 5, and 7, as these bands showed the maximum variance. The organization of the paper is as follows. Section II describes the related work. Section III provides the framework for the proposed approach. Section IV deals with the experiment and results, and the whole study is concluded in Section V.

## II. RELATED WORK

In remote sensing data are obtained as multispectral images. Many ML algorithms are being used to classify pixels in a multispectral image. The conventional ML techniques for classification require the sample in the form of a feature vector. In classifying Landsat-8 scene, each pixel is represented by a feature vector obtained by reflectance values in different spectral bands. A few small homogeneous areas representing distinct categories on the ground are identified and the feature vectors associated with pixels in those training areas are used to generate training set data. Conventional ML techniques include the maximum likelihood classifier (MLC), decision tree (DT), support vector machine (SVM), Random Forest (RF), multi-layer perceptron model, and fuzzy inference system. The maximum likelihood classifier assumes normal distribution of reflectance values and is commonly used in remote sensing applications. Huang et al. [7] have used the SVM to classify pixels in multispectral images and their model obtained higher accuracy. The SVM is appealing for Landsat data analysis because it classifies small data sets with high accuracy [8]. Moumtrakis et al. [9] have provided a review of usage of SVM in remote sensing. Another commonly used algorithm to classify pixels in multispectral images is a decision tree (DT). The main problem with the DT is overfitting. DT shows high accuracy with the training data, however; it may not perform well in classifying unknown data samples. Lowe and Kulkarni [10] used the random forest algorithm for classification of pixels in Landsat data.

CNN models represent one of the best learning algorithms for understanding image contents and have shown exemplary performance in computer vision tasks. CNN models use multiple layers of nonlinear information processing units. Machine-learning community's interest in CNN grew after Image-Net competition in 2012, where Alex Net achieved record breaking results in classifying images from the dataset containing more than 1.2 million images from one thousand classes. Alex Net proposed by Krizevsky et al. [11] was based on principles used in LeNet. DCNNs have brought about breakthroughs in processing images, videos, speech, and audio [12]. In general CNN models consists of convolution and pooling layers that are grouped followed by one or more fully connected layers. They are feed-forward networks. In convolution layers, inputs are convolved with a weighted kernel and the output is sent via a nonlinear activation function to the next layer. The purpose of the pooling layer is to reduce spatial resolution. Rawat and Wang [13] provide a comprehensive survey of CNNs. Zhang et al. [14] provide taxonomy of CNN models. CNNs can learn internal representations from raw pixels and are hierarchical learning models that can extract features [15, 16]. Liu et al. [17] provide a survey of deep neural network architectures and their

applications. Khan et al. [18] in their review article classified DCNN architectures into seven categories. Deep learning allows computational models that are composed of multiple processing layers to learn representations of data with multiple levels of abstraction. Recent developments in CNN models were possible because of the availability of faster graphical processing units (GPUs) and availability of large data sets. Kulkarni in [19] used the Alex Net to classify two image datasets. The first dataset contained four hundred animal images of two types of animals and obtained 99.1 percent accuracy. The second dataset contained four thousand images of five types of flowers and obtained 86.64 percent accuracy.

Remote sensing images are often obtained in multiple spectral bands. Traditional ML are used to classify pixels in multispectral images, where each pixel is represented by a feature vector consisting of reflectance values from different spectral bands. There is a great deal of research directed towards CNN architectures for RGB images, while a relative dearth of research directed towards CNN architectures for multispectral and hyperspectral images. Many DCNN models have been deployed to analyze remote sensing data. Castelluccio et al. [20] explored the use of CNN models for semantic classification of remote sensing scenes. They resort to pre-trained CNNs that are only fine-tuned on the target data to avoid overfitting problems and reduce design time. Liu [21] used R-CNN for multispectral pedestrian detection task and then modeled it into a convolution network (ConvNet) for the fusion problem. Xu et al. [22] proposed a CNN framework to extract spectral-spatial features from hyperspectral imagery (HIS) and light detection and ranging (LiDAR) data, and to combine HIS and LiDAR data. Chen et al. [23] used Faster R-CNN for airport detection from Landsat images. Their experimental results show that for the same training samples their CCN based approach outperforms traditional SVM and state-of-the-art CNN based methods. Senecal et al. [24] have created a small CNN architecture capable of being trained from scratch to classify 10 band multispectral images. Osorio et al. [25] used a deep learning approach for weed detection. They used a method YOLOV3 (you only look V3), taking advantage of robust architecture for object detection. Garcia et al. [26] studied the use of different CNN architectures for cloud masking in multispectral images. Yuan et al. [27] proposed a novel DCNN architecture that outperforms the state-of-the-art DCNN-based water body detection methods. Wu et al. [28] proposed a deep-learning-based new framework for multimodal remote sensing data classification.

Tabular data are the most used data. DCNN models have shown excellent performance and have therefore been widely adapted. However, their adaptation to tabular data remains highly challenging. Borisov, et al. [1] provide an overview of deep learning methods for tabular data. They categorize these methods into three groups a) data transformations, b) specialized architectures, c) regularization models. In this work we consider the first category data transformations. DCNNs offer multiple advantages over traditional ML techniques. First, they are flexible and allow iterative learning. Second, tabular data generation is possible using deep networks and can help mitigate class imbalance problems. Third, neural networks can be deployed for multimodal learning problems where tabular

data can be one of many input modalities [1]. To our knowledge there are very few methods that have been reported for analyzing tabular data using CNN models. Sharma et al. [2] developed a method called DeepInsight to transform non-image data to images for CNNs. Their method constructs an image by placing similar features together and dis-similar ones further apart enabling the collective use of neighboring elements. This collective approach of element arrangements can be useful in understanding relationships between a set of features. They employed four distinct kinds of datasets to evaluate their algorithm. They compared the obtained results to state-of-the art classifiers such as the decision tree, Ada-boost, and random forest. Their model had shown better classification accuracy for all datasets. Buturovic and Mitkovic [29] proposed algorithm called TAC (table to convolution) to embed a feature vector into image. They used the base-image, and the feature vector is used as a kernel to obtain the convolved image. Zhu et al. [3] have suggested a method called Image Generator for Tabular Data (IGTD) to transform tabular data into images by assigning features to pixel positions so that similar features are close to each other. The algorithm assigns each feature to a pixel in the image. An image is generated for each data sample, in which the pixel intensity reflects the value of the corresponding feature in the sample. The algorithm searches for the optimized assignment of features to pixels by minimizing the difference between the ranking of the pairwise distances between features and the raking pairwise distances between assigned pixels. To investigate the utility of the IGTD, they applied the algorithm to two datasets CCL gene expression and drug molecular descriptors. They transformed these tabular datasets into images and classified them using CNN. Their results show that the CNNs trained on IGTD images provide the highest average prediction performance in cross-validation on both datasets. Kulkarni [30] has proposed a method to map tabular data into images. Each feature vector is mapped to an image. The number of mapped regions in the image is equal to the number of features and the gray values of the regions represent feature values. The algorithm was used to classify a dataset representing URLs for phishing detection. Sun et al. [4] have proposed a method to convert tabular data into images called SuperTML. The algorithm borrows the concept of the Super Characters method to address tabular data machine learning tasks. For each input tabular features are first projected onto a two-dimensional embedding and fed into fine-tuned two-dimensional CNN models for classification. They validated the algorithm by using four datasets. Their experimental results show that SuperTML method has achieved state-of-the-art results on both large and small tabular datasets.

## III. PROPOSED FRAMEWORK

In machine learning approaches such as decision tree, support vector machine, models are trained using feature vectors from the training set data. In our method, we convert feature vectors into images, which are saved in DataMart. Images are saved in the folders that are labeled with class names. The CNN model is trained with images in Datamart. The framework for the CNN training is shown in Fig. 1. The crucial step in the proposed approach is to convert a feature vector into a 2-D image matrix. In the proposed approach the output image contains $n^2$ rectangles, where $n$ represents the number of features in the feature vector. For example, if there are five features in the feature vector, the corresponding output image contains twenty-five rectangular shapes. The areas diagonal squares represent the features, and the areas of the off-diagonal rectangles represent ratios of the features as shown in Eq. (1), where $A_{ij}$ represents the area of the shape, $i$ and $j$ represent. the row and the column numbers of the shape and $f_i$ represents a feature $i$.

$$A_{ij} = \begin{cases} \left(\dfrac{f_i}{f_j}\right) & if\ i \neq j \\ \left(f_i^2\right) & if\ i = j \end{cases} \tag{1}$$
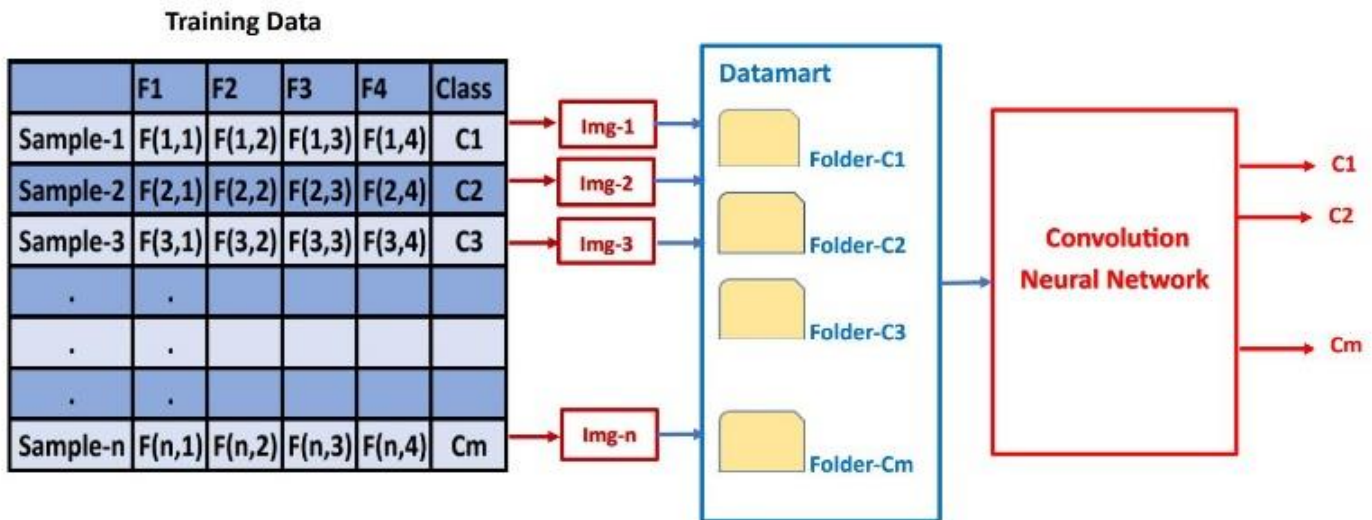


Fig. 1. Framework for CNN learning.

It can be seen from Fig. 2 that the widths and heights of diagonal rectangles represent feature values. The widths of the off-diagonal rectangles represent feature values, and heights of the off-diagonal rectangular shapes represent inverse of feature values.
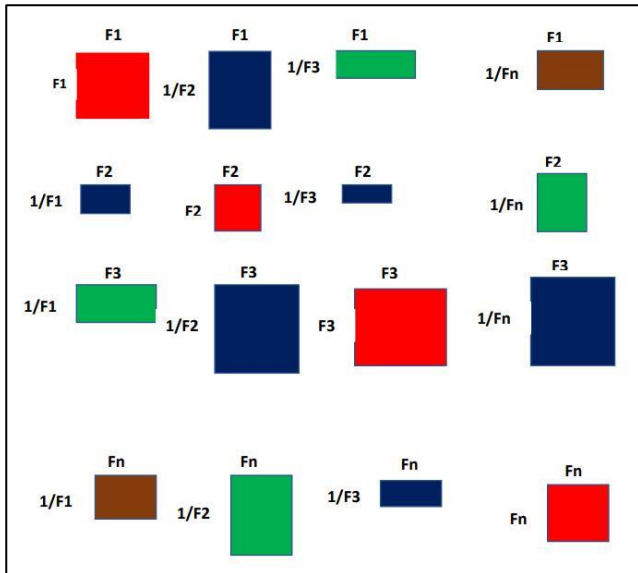


Fig. 2. Mapped image with n features.

Layers of a DCNN include the input layer, convolution layer, batch normalization layer, ReLU layer, max pooling layer, fully connected layer, SoftMax layer, and classification layer. We can specify the input image size at the input layer. Convolution layers serve as feature extractors. Inputs are convolved with learned weights to compute feature maps and results are sent through a nonlinear activation function. The output of the $k^{th}$ feature map is given in Eq. (2).

$$Y_k = f\left(W_k * x\right) \quad (2)$$

where, $x$ denotes the input image, $W_k$ is the convolution filter. The '*' sign refers to the 2-D convolution operator [13] The batch normalization layers normalize the activations and gradients propagating through the network, which makes the training an easier optimization problem. The batch normalization layers are followed by ReLU layers. The purpose of the pooling layer is to reduce the spatial resolution by downsizing and extract invariant features. The max pooling layer is used to downsize the network and extract features. The fully connected, SoftMax and classifier layers map the feature vector to class labels. The output of the SoftMax layer consists of positive numbers that sum up one that are used as class probabilities. We used Alex Net to classify feature vectors. Layers of Alex New are shown in Fig. 3. The model consists of eight layers: five convolution layers and three fully connected layers.
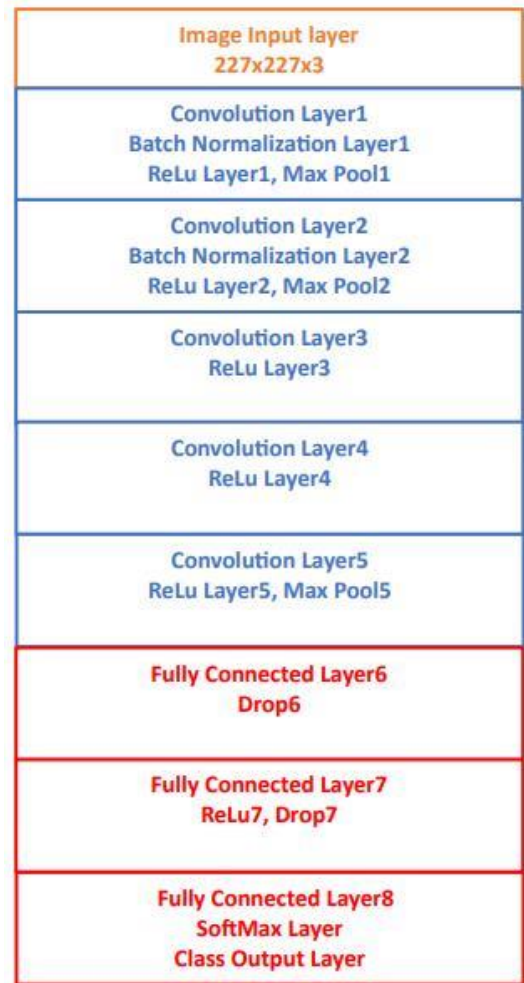


Fig. 3. Layers of alex net.

## IV. EXPERIMENT AND RESULTS

We developed software to map tabular data into images using MATLAB script. The output images were stored in their respective class folders. We also implemented Alex Net using the MATLAB toolbox. The DCNN model was trained with images that were generated from feature vectors in tabular training set data. We classified pixels from two sub-scenes using the trained DCNN model. We considered Landsat-8 scenes that were obtained by Operational Land Imager (OLI).

### A. Example-1 New Orleans Scene

The scene was obtained by Landsat-8 OLI on February 26, 2016. The path and row numbers for the scenes are 22 and 39, respectively. To generate the training set data, we considered the scene of the size 1000 by 1000 pixels. Three small homogeneous areas were selected as training sets that represent three classes water, land, and vegetation. The training set data contains 600samples, 200 from each class. We selected band-2, band-3, band-4, band-5, and band-7. The spectral signatures obtained from mean vectors of the classes are shown in Fig. 4. During training, feature vectors are mapped to images. Each image represents a feature vector representing a pixel in the multispectral image. The mapped images were stored in their

respective class folders. These images were used to train and validate Alex Net. We used 70 percent randomly selected images for training and 30 percent for validation. With Alex Net we obtained the overall accuracy of 98.33 percent. The learning progress curve for Alex Net is shown in Fig. 5. The confusion matrix is shown in Fig. 6 and the ROC curves are shown in Fig. 7. We used the trained network models to classify sub-scene of the size 256 by 256 pixels. Fig. 8 shows the classified scenes for the New Orleans area.



Fig. 7.   ROC curve New Orleans scene.
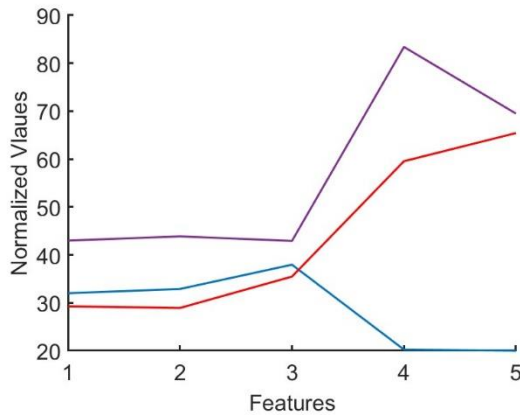


Fig. 4.   Spectral signatures for New Orleans scene.
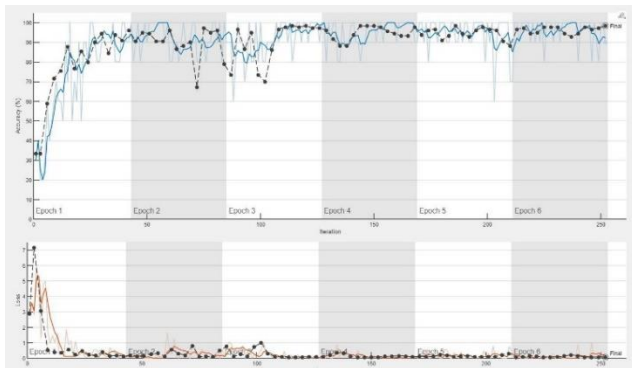


Fig. 5.   Training progress curve for New Orleans scene.
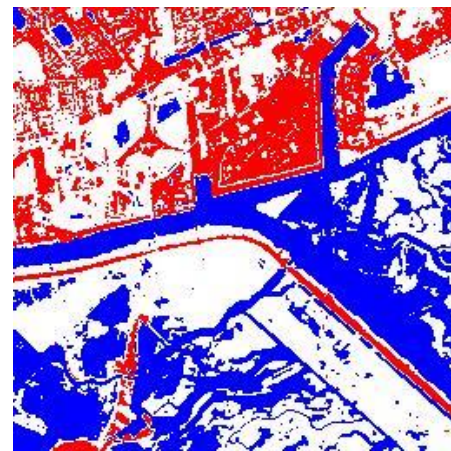


Fig. 8.   Classified New Orleans scene.

### B.  Example-2 Juneau Alaska Scene

The scene was obtained by Landsat-8 OLI on June 13, 2016. The path and row numbers for the scene are 58 and 19, respectively. To generate the training set data, we considered the scene of the size 1000 by 1000 pixels. Four small homogeneous areas were selected as training sets that represent four classes' water, vegetation, ice-land, and glaciers.

The training set data contains 400 samples, 100 from each class. We selected band-2, band-3, band-4, band-5, and band-7 as features. The spectral signatures obtained from mean vectors of the classes are shown in Fig. 9. During training, feature vectors mapped into images. Each image represents a feature vector representing a pixel in the multispectral image. The mapped images were stored in their respective class folders. These images were used to train Alex Net. We used 70 percent randomly selected images for training and 30 percent for validation. We obtained the overall accuracy of 98.33 percent. The learning progress curve for Alex Net is shown in Fig. 10. The confusion matrix is shown in Fig. 11 and ROC curves are shown in Fig. 12. We used a trained network model to classify sub-scene of the size 256 by 256 pixels. The classified scene is shown in Fig. 13.



Fig. 6.   Confusion matrix New Orleans scene.
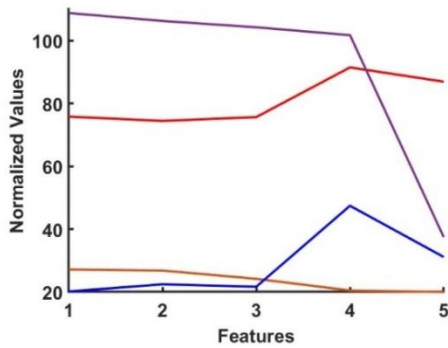
Fig. 9. Spectral signatures for Alaska scene.
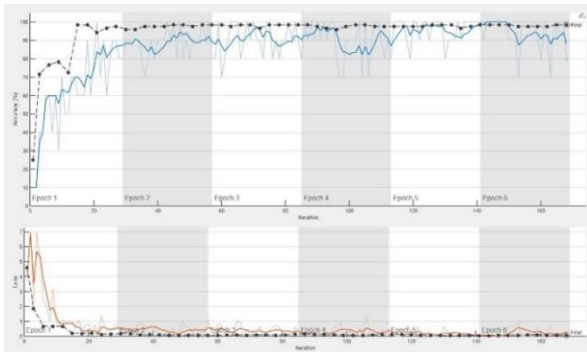


Fig. 10. Training progress curve Alaska scene.
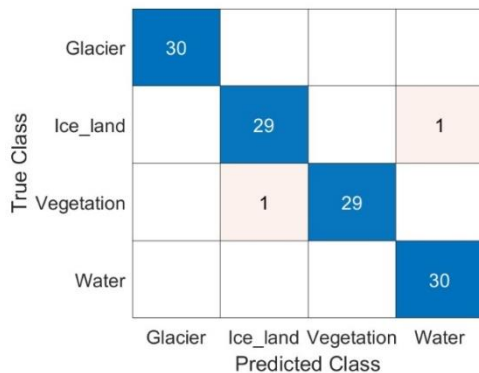


Fig. 11. Confusion matrix Alaska scene.
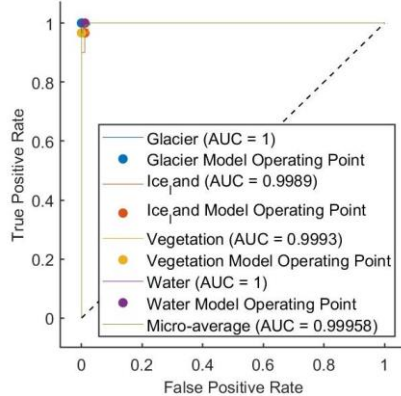


Fig. 12. ROC curve Alaska scene.
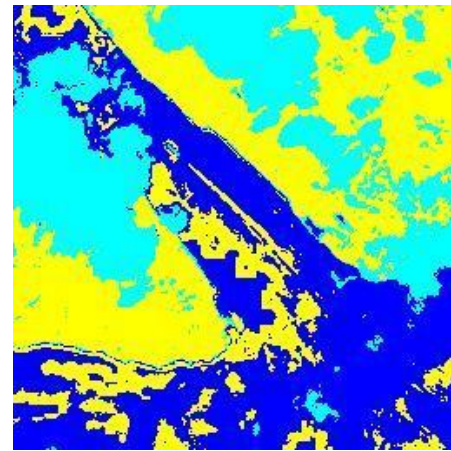


Fig. 13. Classified Alaska scene.

## C. Comparison of Classifier Results

We also classified both datasets using DT, SVM, and RF algorithms. The results are shown in Table I. It can be seen from the results that the proposed algorithm provides state-of-the-art results.

TABLE I. OVERALL ACCURACY

| *Dataset* | *Decision Tree* | *Support Vector Machine* | *Random Forest* | *Alex Net* |
|---|---|---|---|---|
| New Orleans Scene | 98.33 % | 97.50 % | 97.50 % | 98.33 |
| Alaska Scene | 96.11 % | 97.22 % | 98.89 | 98.33 |

## V. CONCLUSIONS

In this paper, we proposed a new method to classify tabular data using CNNs. We used the proposed method to classify pixels in a multispectral image. We developed the algorithm and implemented it using MATLAB script. We analyzed two Landsat-8 scenes, one from the New Orleans area and another from the Alaska area. The training set data for these scenes were generated by selecting small homogeneous areas from the displayed scenes. Feature vectors were mapped to images that were used to train the DCNN model. The results show that the proposed approach yields the state-of-the-art results. The limitation of the proposed approach is that the number of features that can be processed. This is due to the limit on the number of rectangular regions that can be accommodated in a transformed image. The maximum size of the transformed image is finite which limits the number of shapes in the transformed image. The future work includes using other complex shapes to represent feature values and using DCNN models such as Resnet-50 and Google Net so that the overall accuracy can be improved. Also, we would like to extend the algorithm for remote sensing images with a greater number of spectral bands.

REFERENCES

[1] V. Borisov, T. Leemann, K. Seßler, J. Haug, M. Pawelczyk and G. Kasneci, "Deep Neural Networks and Tabular Data: A Survey," in IEEE Transactions on Neural Networks and Learning Systems, doi: 10.1109/TNNLS.2022.3229161.

[2]  A. Sharma, E. Vans, D. Shigemizu, K. A. Boroevich, and T. Tsunoda, "Deep Insight: A methodology to transform a non-image data to an image for convolution neural network architecture." Nature Sci Rep 9, 11399, 2019.

[3]  Y. Zhu, T.Brettin, F. Xia, A. Partin, M. Shukla, H. Yoo, Y. A. Evrard, J. H. Doroshow, and R. L. Stevens, "Converting tabular data into images for deep learning with convolutional neural networks" Nature Scientific Reports, 2021 https://doi.org/10.1038/s41598-021-90923-y

[4]  B. Sun et al., "SuperTML: Two-Dimensional Word Embedding for the Precognition on Structured Tabular Data," 2019 IEEE/CVF Conference on Computer Vision and Pattern Recognition Workshops (CVPRW), Long Beach, CA, USA, 2019, pp. 2973-2981, doi: 10.1109/CVPRW.2019.00360.

[5]  D. N. Thi, N. T. T. Ha, Q. T. Dang, K. Koike, and N. M. Trong, "Effective band ratio of Landsat 8 Images based on VNIR-SWIR reflectance spectra of topsails for soil moisture mapping in a tropical region, Remote Sens. 2019, vol. 11, no. 6, 716; https://doi.org/10.3390/rs11060716

[6]  USGS-Landsat-8 https://www.usgs.gov/landsat-missions/landsat-8

[7]  C. Huang, L. Davis, and J. Townshend, "An assessment of support vector machines for land cover classification," International Journal of Remote Sensing, vol. 23, no. 4, pp. 725-749, 2002.

[8]  P. Mantero, G. Moser, and S. B. Serpico, "Partially supervised classification of remote sensing images through SVM-based probability density estimation," IEEE Transactions on Geoscience and Remote Sensing, vol. 43, no. 3, pp. 559-570, 2005.

[9]  G. Mountrakis, J. Im, and C. Ogole, "Support vector machines in remote sensing: A review," ISPRS Journal of Photogrammetry and Remote Sensing, vol. 66, no. 3, pp. 247-259, 2011.

[10] B. Lowe and A. D. Kulkarni. "Multispectral image analysis using Random Forest," International Journal on Soft Computing (IJSC), vol. 6, no.1, pp. 1-14, 2015.

[11] A. Krizhevsky, I. Sutskever, G. Hinton, "ImageNet classification with deep convolutional neural networks." Adv Neural Inf Process Syst. 2012 https://doi.org/10.1061/(ASCE)GT.1943-5606.0001284

[12] Y. LeCun, Y. Bengin, and G. Hinton, "Deep learning," Nature, vol. 521, pp. 436-444, 2015.

[13] W. Rawat, and Z. Wang, "Deep convolution neural networks for image classification: A comprehensive review," Neural Computation, vol. 29, pp. 2352-2449, 2017

[14] S. Zhang, L. Yaq, A. Sun, Y. Tay, "Deep Learning based Recommender System: A Survey and New Perspectives," ACM Computing Surveys, 2018, vol. 1, no. 1, pp. 1-35.

[15] Q. Abbas, M. Ibrahim, M. Jaffar (2019) A comprehensive review of recent advances in deep vision systems. Artif Intell Rev, 2019, vol. 52, pp 39–76. https://doi.org/10.1007/s10462-018-9633-3

[16] Y. Guo, Y. Liu, A. Oerlemans, S. Lao, S. Wu, and M. S. Lew, "Deep learning for visual understanding: A review," Neurocomputing, 2016, vol. 187, pp. 27–48.

[17] W. Liu, Z. Wang, X. Liu, N. Zeng, Y. Liu, and F. F. Alsaadi, "A survey of deep neural network architectures and their applications," Neurocomputing, 2017, vol. 234, pp.11-26.

[18] A. Khan, A. Sohail, U. Zahoora, A. S. Qureshi, "A Survey of the Recent Architectures of Deep Convolutional Neural Networks," Artificial Intelligence Review, 2020, vol. 53, pp. 5455–5516. https://doi.org/10.1007/s10462-020-09825-6.

[19] A. D. Kulkarni, "Deep Convolution Neural Networks for Image Classification," International Journal of Advanced Computer Science and Applications, Vol. 13, No. 6, pp 18-23, 2022.

[20] M. Castelluccio, G. Poggi, C. Sansone, and L. Verdoliva, "Land use classification in remote sensing images by convolutional neural networks," arXiv:1508.00092v1 [cs.CV] 1 Aug 2015

[21] J. Liu, S. Zhang, S. Wang, D. N. Metaxas, "Multispectral Deep Neural Networks for Pedestrian Detection," Computer Vision and Pattern Recognition, arXiv:1611.02644[cs.CV] https://doi.org/10.48550/arXiv.1611.02644

[22] X. Xu, W. Li, Q. Ran, Q. Du, L. Gao, B. Zhang, "Multisource remote sensing data classification based on convolutional neural network," IEEE Transactions on Geoscience and Remote Sensing, vol. 56, no. 2, 2018, pp 937-949.

[23] F. Chen, R. Ren, T. V. Voorde, W. Xu, G. Zhou, and Y. Zhou, "Fast automatic airport detection in remote sensing images using convolutional neural networks," Remote Sens. 2018, vol. 10, 443; doi:10.3390/rs10030443

[24] J. J. Senecal, J. W. Sheppard, and J. A. Shaw, "Efficient convolutional neural networks for multi-spectral image classification," IJCNN 2019. International Joint Conference on Neural Networks. Budapest, Hungary. 14-19 July 2019, paper N-19045.

[25] K. Osorio O, A. Puerto, C. Pedraza, D. Jamaica, and L. Rodríguez, "A Deep Learning Approach for Weed Detection in Lettuce Crops Using Multispectral Images," Agri Engineering vol 2, No. 3, pp. 471-488, 2020; https://doi.org/10.3390/agriengineering2030032

[26] G. M. Garca, L. G. Chova, G. C. Valls, "Convolution neural networks for multispectral image cloud masking," arXiv:2012.05325v1 [cs.CV], 2020.

[27] K. Yuan, X. Zhuang, G. Schaefer, J. Feng, L. Guan, and H. Fang, "Deep-learning-based multispectral satellite image segmentation for water body detection, IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, vol. 14, 2021, pp 7422-7434.

[28] X. Wu, D. Hong, and J. Chanussot, "Convolutional Neural Networks for Multimodal Remote Sensing Data Classification," in IEEE Transactions on Geoscience and Remote Sensing, vol. 60, pp. 1-10, 2022, Art no. 5517010, doi: 10.1109/TGRS.2021.3124913.

[29] L. Buturovic and D. Miljkovic, "A novel method for classification of tabular data using convolution neural networks" 2020. https://doi.org/10.1101/2020.05.02.074203

[30] A. D. Kulkarni "Convolution Neural Networks for Phishing Detection," International Journal of Advanced Computer Science and Applications, vol. 14, no. 4, 2023, pp 15-19.

# Comparison of Four Demosaicing Methods for Facial Recognition Algorithms

M. Eléonore Elvire HOUSSOU[1], A. Tidjani SANDA MAHAMA[2], Pierre GOUTON[3], Guy DEGLA[4]

ImVIA, University of Bourgogne, Dijon, France[1, 2, 3]
IMSP, University of Abomey-Calavi, Dangbo, Benin[1, 2, 4]

*Abstract*—Multispectral imaging has become more important in several areas during this decade to overcome the limitations of color imaging. There are several types of multispectral acquisition systems, including single-shot cameras that incorporate Multispectral Filter Arrays (MSFA). MSFA is an extension of the color filter array. Acquisition systems that incorporate spectral filter arrays are very fast, lightweight, and able to acquire moving scenes. But these cameras are manufactured with at best software for filter positioning correction without demosaicing software. Hence there is a need to identify a suitable demosaicing algorithm in terms of image quality, computation time, and decorrelation factor. This paper presents a comparative study of four relevant demosaicing methods in the facial recognition process using images acquired with a single-shot MSFA camera designed in our laboratory. To achieve this goal, the four demosaicing methods named bilinear interpolation, discrete wavelet transform, binary tree, and median vector were adapted to multispectral images acquired using a MSFA camera. Evaluations were first performed using the NIQE performance metric and the correlation coefficient. Then Demosaced images were used to train VGG19 neural network to know which demosacing method better contains relevant features for recognition and better computation time. Results reveal that bilinear interpolation provides the less correlated images and the binary tree gives the best quality images with a NIQE of 8.99 and an accuracy of 100% for face recognition.

*Keywords*—*Multispectral image database; multispectral imaging; multispectral filter array (MSFA); one-shot camera; facial recognition system*

## I. INTRODUCTION

Most of today's color cameras incorporate color Filter Array (CFA) or Bayer filters [1], [2]. The color filter array contains three filters: green, red, and blue, each one responsible for acquiring the image in each spectral band. These cameras are very fast, displaying the acquired image in a matter of seconds. Despite this performance, facial recognition [3] with color cameras is affected by problems of light variations, occlusions, and pose variations [4], [5]. Multispectral imaging corrects these problems, with more information available in the image bands. There are three types of multispectral acquisition systems: multi-camera systems, multi-sensors systems, and one-shot MSFA systems. The first two types are very slow, heavy, and consume more energy. One-shot MSFA cameras help to overcome the problems associated with the other two types. The one-shot MSFA cameras are equipped with MSFA which is an extension of CFA [6]–[8]. The MSFA includes more than three filters. Each filter is responsible for the acquisition of the image on a given wavelength. The acquisition systems that incorporate the multispectral filters array allow the acquisition of a single image on several spectra simultaneously. These are compact, one-shot cameras, very fast, and capable of capturing moving scenes. MSFA one-shot cameras solve the problems associated with conventional multispectral cameras, which are the heaviness and slowness during the acquisition of multispectral images. MSFA one-shot cameras are used in several fields such as agriculture, medical imaging, and pattern recognition [9]–[12].

A recognition system is composed of four main modules namely acquisition, feature extraction, matching, and decision. The performance of the system depends on each of the modules. There are several facial recognition systems in the multispectral but most of them use multispectral cameras consisting of multiple single-shot cameras or a single-shot camera in scanning mode. For the acquisition module, a database of face images was collected with a single-shot MSFA camera for facial recognition. This camera is mainly equipped with a viiamagic CMOS sensor, a MSFA with eight filters, micro-lens, an electronic board to drive the sensor, and a camera board for image acquisition. The MSFA bands were selected theoretically with a genetic algorithm combined with a facial recognition application [13]. This acquisition system covers the spectral range from 650 to 950 nm and produces raw or mosaic images which require demosaicing before use. Demosaicing is a method of estimating the value of missing pixels in a given band. At the end of demosaicing the number of multispectral images obtained is equal to the number of filters that compose the MSFA. Some demosaicing methods [14]–[18] are developed during the theoretical design of the MSFA, but the industrial constraints of MSFA manufacturing mean that effective demosaicing methods are developed after the MSFA is manufactured. In this case, we already have a MSFA camera, and we want to determine suitable demosaicing methods using its images. Demosaicing methods impact the image quality and thus the performance of the facial recognition system with a single-shot MSFA camera. Single-shot MSFA cameras are very efficient and fast, but the quality of the demosaic images depends on the demosaicing method used.

This paper presents the comparative study of four demosaicing methods to identify the one that gives:

- The best image quality result.

- The best decorrelation factor.

- The best facial recognition score.

- And the best computation time.

For these purposes, we adapted some currently used algorithms namely demosaicing algorithms Bilinear Interpolation, Discrete Wavelet Transform (DWT), Binary Tree, and Median Vector to demosaic the images acquired with our camera. A comparison of the demosaiced images is made with the NIQE metric and the intercorrelation between the demosaiced image bands is analyzed with the coefficient correlation. The convolutional neural network VGG19 is used to evaluate the impact of demosaicing on facial recognition in terms of accuracy and computation time. To the best of our knowledge, this is the first study that focuses on demosaicing after the MSFA camera is manufactured.

This paper is structured as follows: Section II briefly presents the MFSA one shot camera, material and methods in Section III, followed by experimental results and discussion in Section IV. The paper ends with the conclusion and future perspectives in Section V.

## II. THE MSFA ONE SHOT CAMERA

Multispectral imaging with a single camera equipped with a spectral or multispectral filter array allows acquiring multispectral images simultaneously on several spectral bands. The concept of a multispectral filter array is an extension to n bands of the color filter array that revolutionized digital cameras. A spectral filter array is composed of n filters and each of them is responsible for the acquisition of the image on a given band. The MSFA camera used in this work is composed of a single Viimagic 9220H sensor, an MSFA for the single-tap imaging system, optical lenses, an electronic board to drive the sensor, and a camera board for image acquisition. This acquisition system was designed in the Imaging and Artificial Vision (ImViA) laboratory formerly known as the Laboratory of Electronics, Informatics, and Image (LE2I) as part of the EU H2020 project called EXIST (Extended Image Sensing Technologies) [13]. It is a light and compact camera that covers wavelengths from 650 to 950 nm. The spectral filter array integrated into this camera is made up eight optimal filters selected in the wavelengths {685, 720,770, 810, 835, 870, 895,930}. The design of this custom filter array uses the Fabry-Perot interferometer. The MSFA system integrated into this camera with dedicated hardware and software calculations allows working in real time with 30 frames per second. The filters used to overcome the problems caused by illumination variation, motion blur noise, and SNR noise that severely affect the performance of facial recognition systems using CMOS. The multispectral filter array is characterized by its moxel which is defined by a mosaic of elementary filters repeated across an MSFA. Fig. 1 illustrates the moxel used.
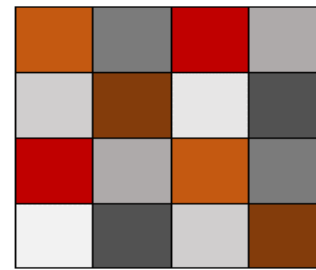


Fig. 1. Final moxel of the MSFA.

## III. METHODS

### A. Motivation

The literature distinguishes three categories of demosaicing methods: pixel interpolation, frequency transformation, and probability of appearance (POA). Pixel interpolation consists in using the value or weight of neighboring pixels to estimate the value of a missing pixel. Methods such as bilinear interpolation, weighting bilinear interpolation, and binary tree use pixel interpolation. Frequency transformation involves using wavelets to extract essential information from neighboring pixels to estimate the value of the missing pixel. Frequency transformation includes methods such as Discrete Wavelet Transform. Probability of appearance refers to methods that determine the probability of the occurrence of a band and a pixel in a selected band to estimate the value of the missing pixel. These methods include approaches based on binary trees. In general, demosaicing methods depend on the MSFA moxel but nowadays there are generic demosaicing methods that can be adapted to any type of MSFA. Discrete Wavelet Transform, Bilinear Interpolation, Binary three, and vector median filtering were selected for the comparative study. These four demosaicing methods were selected because each one presents some interesting characteristics for the study. These were chosen for the following reasons:

- Bilinear interpolation uses the value or weights of neighboring pixels to estimate a missing pixel in a given band. Most demosaicing algorithms combine their demosaicing technique with bilinear interpolation [17], [19]–[21].

- Binary Tree-based Edge-Sensing method is a generic approach that uses the notion of POA to select the band and the pixel in the selected band. This method combines POA, and bilinear interpolation based on the edge–sensing information [22] to determine the value of the missing pixel.

- Discrete Wavelet Transform based MSFA demosaicing [17] is a technique that uses frequency information and Weighted Bilinear interpolation to approximate the value of the missing pixel.

- Vector median filtering [23] is a demosaicing method whose specificity is to use vector based operations and the concept of pseudo pixel. This method groups neighboring pixels according to the size of the moxel to evaluate the value of the pixel missing.

## B. Preprocess

The images acquired with the MSFA one-shot cameras are raw images or mosaic images and must be process or demosaic before using. Demosaicing is a technique that consists in reconstructing each band of the multispectral according to the number N (N=8 in this study) of filters contained in the MSFA. Before demosaicing, a preprocess of band extraction is first performed. This preprocess consists in multiplying each mosaic image by different binary masks $M^k$ as defined by the Eq. (1).

$$M^k_{(x,y)} = \begin{cases} 1 \ si \ \left( x \ mod \ \sqrt{K} \right) + \left( y \ mod \ \sqrt{K} \right) \times \sqrt{K} = k \\ 0 \ else \end{cases} \quad (1)$$

This transformation gives eight planes of shifted images in which only one component is available at each pixel. Fig. 2 illustrates this transformation.
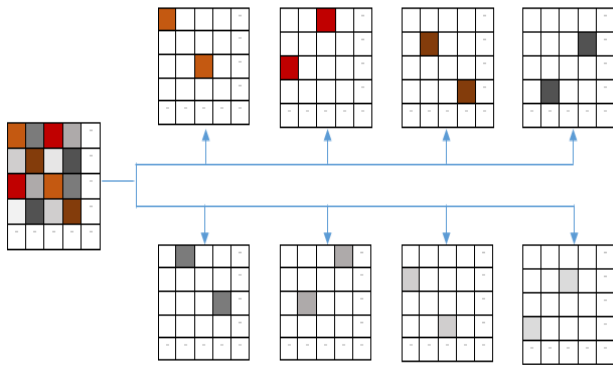


Fig. 2. Images bands obtained after applying the mask.

After pre-processing, the missing pixels in each image band are estimated using the four selected demosaicing methods.

## C. Bilinear Interpolation based MSFA Demosaicing

The bilinear interpolation based demosaicing is the simplest method for calculating the value of pixels missing during the demosaicing process. Other demosaicing methods combine their specificities with bilinear interpolation [24]. Bilinear interpolation approximates each missing pixel value by means of a distance weighted average of its neighboring pixels. As its name indicates, bilinear interpolation is a succession of two linear interpolations. The linear interpolation can be performed in multiple directions. For a missing pixel $P(i,j)$ at position$(i,j)$, the linear interpolation is defined in Eq. (2), Eq. (3) and Eq. (4) as follows:

* Diagonally

$$P(i,j) = \frac{1}{4} \sum_{(m,n)=(-1,-1),(-1,1),(1,-1),(1,1)} p(i+m, j+n) \quad (2)$$

* Vertically

$$P(i,j) = \frac{1}{2} \sum_{(m,n)=(-1,0),(1,0)} p(i+m, j+n), \quad (3)$$

* Horizontally

$$P(i,j) = \frac{1}{2} \sum_{(m,n)=(0,-1),(0,1)} p(i+m, j+n) \quad (4)$$

For this study, a convolution filter $H$ is used for demosaicing. This filter is defined according to the spatial distance between the neighbors of the central pixel. The interpolated image band $I^k$ is defined by Eq. (5) as:

$$I^k = I'^k \odot H \quad (5)$$

with

$$H = \begin{pmatrix} 5 & 5 & 1 & 1 & 6 & 6 & 8 & 8 & 1 & 1 & 6 & 6 \\ 5 & 5 & 1 & 1 & 6 & 6 & 8 & 8 & 1 & 1 & 6 & 6 \\ 4 & 4 & 8 & 8 & 3 & 3 & 4 & 4 & 5 & 5 & 3 & 3 \\ 4 & 4 & 8 & 8 & 3 & 3 & 4 & 4 & 5 & 5 & 3 & 3 \\ 2 & 2 & 7 & 7 & 5 & 5 & 2 & 2 & 7 & 7 & 8 & 8 \\ 2 & 2 & 7 & 7 & 5 & 5 & 2 & 2 & 7 & 7 & 8 & 8 \\ 5 & 5 & 1 & 1 & 6 & 6 & 8 & 8 & 1 & 1 & 6 & 6 \\ 5 & 5 & 1 & 1 & 6 & 6 & 8 & 8 & 1 & 1 & 6 & 6 \\ 4 & 4 & 8 & 8 & 3 & 3 & 4 & 4 & 5 & 5 & 3 & 3 \\ 4 & 4 & 8 & 8 & 3 & 3 & 4 & 4 & 5 & 5 & 3 & 3 \\ 2 & 2 & 7 & 7 & 5 & 5 & 2 & 2 & 7 & 7 & 8 & 8 \\ 2 & 2 & 7 & 7 & 5 & 5 & 2 & 2 & 7 & 7 & 8 & 8 \end{pmatrix}$$

And $I'^k$ the image band.

## D. Discrete Wavelet Transform based MSFA Demosaicing

A Discrete Wavelet Transform (DWT) is a transform that decomposes a given signal into a number of sets, where each set is a time series of coefficients describing the time evolution of the signal in the corresponding frequency band. When applied to an image, DWT transforms the image into different frequency bands. DWT is used to decompose images into a series of sub-bands with different frequency components. Over the decades, several DWT-based methods have been proposed in [25]–[29] for Color Filters Array (CFA) demosaicing. Xingbo et al. [16] extended the application of DWT into MSFA demosaicing. MSFA demosaicking based on DWT encompasses the concept of Down Sampling images, the Haar wavelet (D2), the "replace" rule for the estimation of high-frequency sub-bands and bilinear interpolation for the estimation of low-frequency sub-bands. This approach is applicable to any MSFA with a regular mosaic pattern, regardless of the number of channels. The algorithm is performed in three successive steps as follows:

* High-frequency estimation: First, the image is divided into K down sampled images and each of them is decomposed into spatial frequency sub-bands by DWT using Haar wavelet. Then, estimate the coefficients of the missing DS images in the high frequency sub-bands according to the "replace" rule.

* Low-frequency estimation: Apply bilinear interpolation to the mosaicked image plane by plane and extract the low frequency by image decomposition using Haar wavelet. Then replace the coefficients of the missing DS images at low-frequency sub-bands with those of the interpolated DS images.

* Recompose the low-frequency and high-frequency components and compute inverse discrete wavelet transform to reconstruct the demosaiced image.

This method has been tested by the authors with CFA and two MSFA of four-bands and eight-bands visible. Given the compatibility of this method with all MSFA with regular patterns, regardless of the number of channels, we have modified it to our eight-bands MSFA described above with two pixels per band. For this algorithm, the wavelengths of the bands have been modified by considering the following wavelengths {685, 720, 770, 810, 835, 870, 895, 930 nm} for the eight bands.

*E. Binary Tree based MSFA Demosaicing*

Lidan Miao et al. [20]–[22] had proposed a generic demosaicing method based on a binary tree. Specifically, this approach uses the Binary Tree Edge Sensing Method (BTES). The missing pixels are estimated progressively using all the edge correlation information of all spectral bands. Binary tree based MSFA demosaicing can be adapted to any $4 \times 4$ MSFA. The generic demosaicing algorithm consists of three interconnected modules: band selection, pixel selection and interpolation [20].

- Band selection: This module defines the interpolation order of the different spectral bands by using the POA. The spectral bands have different POA, and the spectral band with the highest POA contains the most detailed information. Band selection is equivalent to selecting leaf nodes (spectral bands) at different levels of the tree. Nodes located at the same level have the same POA, and the deepest nodes have the smallest POA. The band selection process is described as follows: first, the band with the highest POA is selected, the leaf node at the first level of the binary tree. Then, for levels with more than one leaf, the bands at the next level are randomly selected. Finally, this process is repeated until the last level of the tree.

The band with the most edge information is interpolated first and the edge information from the first interpolated band is used to estimate the other bands.

- Pixel selection: This module determines the order of interpolation of pixel locations in each spectral band. The estimation of the pixel values is done gradually. First, some of the missing pixel values are estimated. The other unknown pixel values are then estimated using these estimated pixel values and the MSFA samples. The algorithm uses the binary tree for the pixel's selection. It takes as input the leaf patterns selected during band selection and interpolates for each of them first the missing band information at the pixel locations where its sibling pattern is located, and then the algorithm goes up one level in the binary tree to find the sibling of its parent pattern. If the latter is an internal node, then the leaf patterns in the subtree below that sibling pattern are examined. This part is repeated until the root of the tree.

- Interpolation is used to estimate the value of the missing pixels with selected pixel for a selected band. The estimate of the value of a pixel $P$ at position $(i, j)$ is calculated by the weighted sum of these four neighboring pixels and their contributions. The weights

of these four pixels are estimated based on their edge magnitudes. The weights of two neighboring pixels along the vertical and horizontally direction are calculated by Eq. (6) and Eq. (7).

Vertically:

$$W_{m,n} = \left(1 + \left|P_{m+2,n} - P_{m,n}\right| + \left|P_{m-2,n} - P_{m,n}\right| + \frac{1}{2}\left|P_{m-1,n-1} - P_{m+1,n-1}\right| + \frac{1}{2}\left|P_{m-1,n+1} - P_{m+1,n+1}\right|\right)^{-1} \quad (6)$$

With $m \in \{i - 1, i + 1\}, n = j$

Horizontally:

$$W_{m,n} = \left(1 + \left|P_{m,n+2} - P_{m,n}\right| + \left|P_{m,n-2} - P_{m,n}\right| + \frac{1}{2}\left|P_{m+1,n-1} - P_{m+1,n+1}\right| + \frac{1}{2}\left|P_{m-1,n-1} - P_{m11,n+1}\right|\right)^{-1} \quad (7)$$

With $m = i, n \in \{j - 1, j + 1\}$

The estimated value $\hat{P}_{i,j}$ of pixel at position $(i,j)$ is defined in Eq. (8).

$$\hat{P}_{i,j} = \frac{\sum_{s,t(|s+t|=1)} W_{i+s,j+t} P_{i+s,j+t}}{\sum_{s,t(|s+t|=1)} W_{i+s,j+t}} \quad (8)$$

The algorithm has been developed for 7 bands. Since the MSFA used has 8 bands, this algorithm was modified for 8 bands, considering the probability of bands appearing.

*F. Vector Median based MSFA Demosaicing*

Gupta et al. [30] had proposed a CFA vector demosaicing algorithm. This approach selects the color vector that minimizes the sum of the distances to the neighboring pixels to estimate the missing colors. This demosaicing approach is based on the notion of pseudo-pixel, which is defined by a group of neighboring values of red, green, and blue pixels (horizontally and vertically). Xingbo et al. [22] had extended this technique for MSFA demosaicing. According to the authors, this method is based on two According to the authors, this method is based on two specificities: first, the pseudo-pixels are formed according to the dimension of a moxel. The Moxel is a mosaic element corresponding to a mosaic of elementary filters repeated via an MSFA. Second, the pseudo-pixels are those that are connected horizontally, vertically, and diagonally.

The median vector $\underline{x}_{VM}$ of $\underline{x}_{1,\dots,}\underline{x}_N$ is defined as follows:

$$\underline{x}_{VM} \in \{\underline{x}_i | i = 1, \dots, N\}$$

For all $j = 1,,,,, N$

$$\sum_{i=1}^{N}\|\underline{x}_{VM} - x_i\|2 \le \sum_{i=1}^{N}\|\underline{x}_j - \underline{x}_i\|2 \quad (9)$$

The algorithm of calculation of the median vector for the demosaicing of the multispectral images proceeds as follows:

- For each vector $x_i$, compute the sum of the distances to all other vectors using the $L^1$-norm or $L^2$-norm as presented in Eq. (10)

$$S_i = \sum_{j=1}^{N}\|\underline{x}_i - \underline{x}_j\|, i = 1, \dots, N \quad (10)$$

- The median vector is $x_{min}$ corresponding to $S_{min}$, which is the minimum of $S_i$

This method was tested by the authors with CFA, 4-bands and 8-bands MSFA. For this algorithm, the wavelengths of the bands have been modified by considering the following wavelengths {685, 720, 770, 810, 835, 870, 895, and 930} nm for the eight bands.

## IV. EXPERIMENTAL RESULTS AND DISCUSSION

### A. EXIST Database and Experimental Setup

EXIST is a multispectral image database that was collected with the MSFA one-shot camera described. The EXIST dataset is composed of 2100 raw images of faces of 105 subjects. Each multispectral image is 2072 x 1104 size. After demosaicing, the images obtained are of size 2072 x 1104x8 each corresponding respectively to the wavelengths {685, 720, 770, 810, 835, 870, 895, 930} in nm. Fig. 3 shows some images of the EXIST database.



Fig. 3. Samples of raw images of EXIST database.

The experiments were carried out on Microsoft System Windows, version 2010, with two computers. The first was equipped with an Intel(R) Core (TM) i7-8565U CPU, 8 GB of RAM memory. The second has a NVIDIA Quadro P400 graphics processing unit (GPU) with 32 GB of Random Access Memory (RAM). All code is written in the MATLAB 2020 and Python 3.7 programming languages.

### B. Evaluation Metrics

To identify a suitable demosaicing algorithm, evaluations were performed on three criteria: image quality, decorrelation factor, and recognition rate, using NIQE, correlation coefficient, and recognition accuracy as metrics, respectively. Based on the literature [31]–[33], there are two types of performance metric for image quality: full reference quality, such as Peak Signal Noise Ratio (PSNR), Structural Similarity Index (SSI), Mean Square Error (MSE) and no-reference quality measurements, such as NIQE, Brisqe and piqe. Since the EXIST image database only contains raw images without references, the NIQE performance measure is used to assess the quality of images demosaiced using different methods.

NIQE is developed by researchers of University of Texas [34]. C.Kawan et al. [35] used NIQE to compare demosaicing method for Mastcam Images. NIQE is no-reference image quality metrics that use statistical features of the input image to evaluate the image quality. To calculate NIQE value, the image is divided into smaller patches, and the features are modeled as MultiVariante Gaussian (MVG) distributions.

After image quality evaluation with NIQE, intercorrelation of demosaiced images is evaluate with correlation coefficient computation. This coefficient allows to identify the degree of similarity between a pair of images. Images are identical when the correlation coefficient is equal to 1. To calculate this correlation coefficient, the method described in [36] was used. Also, to identify the best demosacing method with the best image quality, decorrelation factor, the demosaiced images were used to train four models based on the VGG19 architecture. VGG19 is an architecture of VGGNet proposed by K. Simonyan et al. [37] in 2015. VGG19 contains 19 weight layers consisting of 16 convolutional layers with three fully connected layers and the same five pooling layers. VGG-19 CNN is used as a pre-training model. The accuracy is used to evaluate the images after recognition. Accuracy indicates the percentage of correct prediction.

### C. Result and Discussion

To carry out the test, the following steps were followed for each method:

- Demosaicing raw images.

- Computation of NIQE values and time of demosaiced images.

- Calculation of correlation coefficients between demosaic images.

- Calculation of the average demosaicing.

- Recognition of demosaiced images.

- Computation of recognition time.

This algorithm led to the results presented in Fig. 4.



Fig. 4. Demosaic images by methods.

Visually, we can see that the binary tree presents better images in terms of sharpness of the different parts of the face than the other three demosaicing methods. But visual evaluation alone is not enough. The NIQE metric was therefore used to confirm or invalidate this visual assessment. The quality of the image varies according to the value of NIQE. The smaller the NIQE value, the better the quality of the demosaic image.
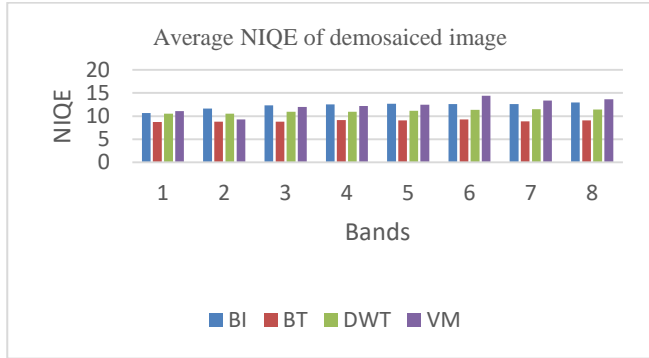


Fig. 5.    Average NIQE of demosaiced image.

The Fig. 5 shows the average NIQE calculated on all images obtained for the four demosaicing methods.

For all demosaicing methods, the NIQE value of the corresponding images varies between 8.75 and 14.38 according to the band and demosaicing method. While the NIQE values of the images demosaiced by bilinear interpolation are between 10.68 and 12.97, those of BT are between 8.75 and 9.29, those of DWT between 10.51 and 11.42, and those of VM between 11.68 and 13.66.

The analysis of the NIQE value per band and per demosaicing method shows that the binary tree has the lowest NIQE value per band and for all methods with average NIQE value of 8.99. Based on this NIQE value, the binary tree provides better quality images than others. This analysis confirms the visual observation made after the experimental results.

Time simulations were then made to compare the four methods. The Figure 6 shows the execution time for each.

Interpretation of Fig. 6 shows that the minimum running time of a demosaicing algorithm is 12.78s and is obtained with bilinear interpolation. This time is slightly less than that of the binary tree. The median vector is the method with the longest execution time. The crossing of the execution time and the NIQE value of the demosaicing algorithms shows that the binary tree is the demosaicing method which allows having best quality images in a reasonable time.

To study the decorrelation factor of demosaiced images, we compute the correlation coefficients between them.

The Fig. 7 shows the average correlation coefficient between each band by demosaicing methods.

The demosaiced images are correlated with an average correlation coefficient of 0.9 for all methods. The analysis of

these different figures allows us to conclude that the intercorrelation factor between the different bands is lower for the Bilinear interpolation than for the other demosaicing methods. Bilinear interpolation allows us to have less correlated images than the other methods.

After the demosaicing process and comparison, the VGG19 convolutional neural network was used for feature extraction and classification of the demosaiced images obtained with each method. The dataset was identical for all the methods. The training and test datasets were separated with random selection with 80% for training, 10% for validation and 20% for test. In all, 2,200 demosaic images of size 300 x 300 pixels, organized into 110 classes and were used.

Tables I to III describe respectively the training parameter of VGG19, the accuracy, and the recognition time for each image by method.
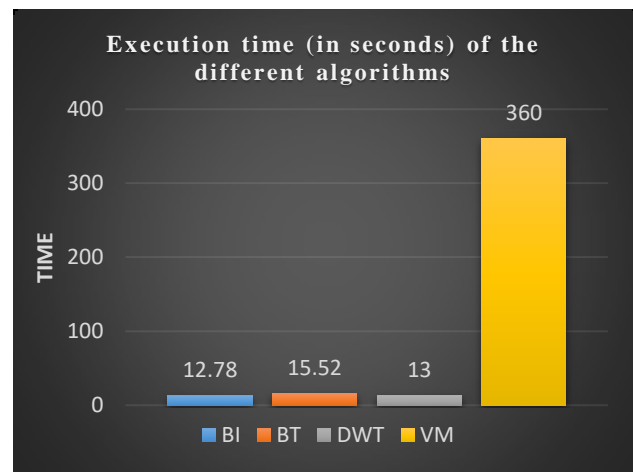


Fig. 6.    Execution time of demosacing algorithms.

TABLE I.    PARAMETERS USED IN THE TRAINING PROCEDURE

| Parameters | VGG19 |
|---|---|
| Batch size | 32 |
| Optimization algorithm | SGD |
| Learning rate | 0.0001 |
| Epoch number | 20 |

TABLE II.    VGG19 RESULT

| Accuracy | BI | DWT | BT | VM |
|---|---|---|---|---|
| VGG19 | 100 | 89 | 100 | 80 |

TABLE III.    EXECUTION TIME

| Accuracy | BI | DWT | BT | VM |
|---|---|---|---|---|
| Time(s) | 3 | 4 | 2 | 6 |
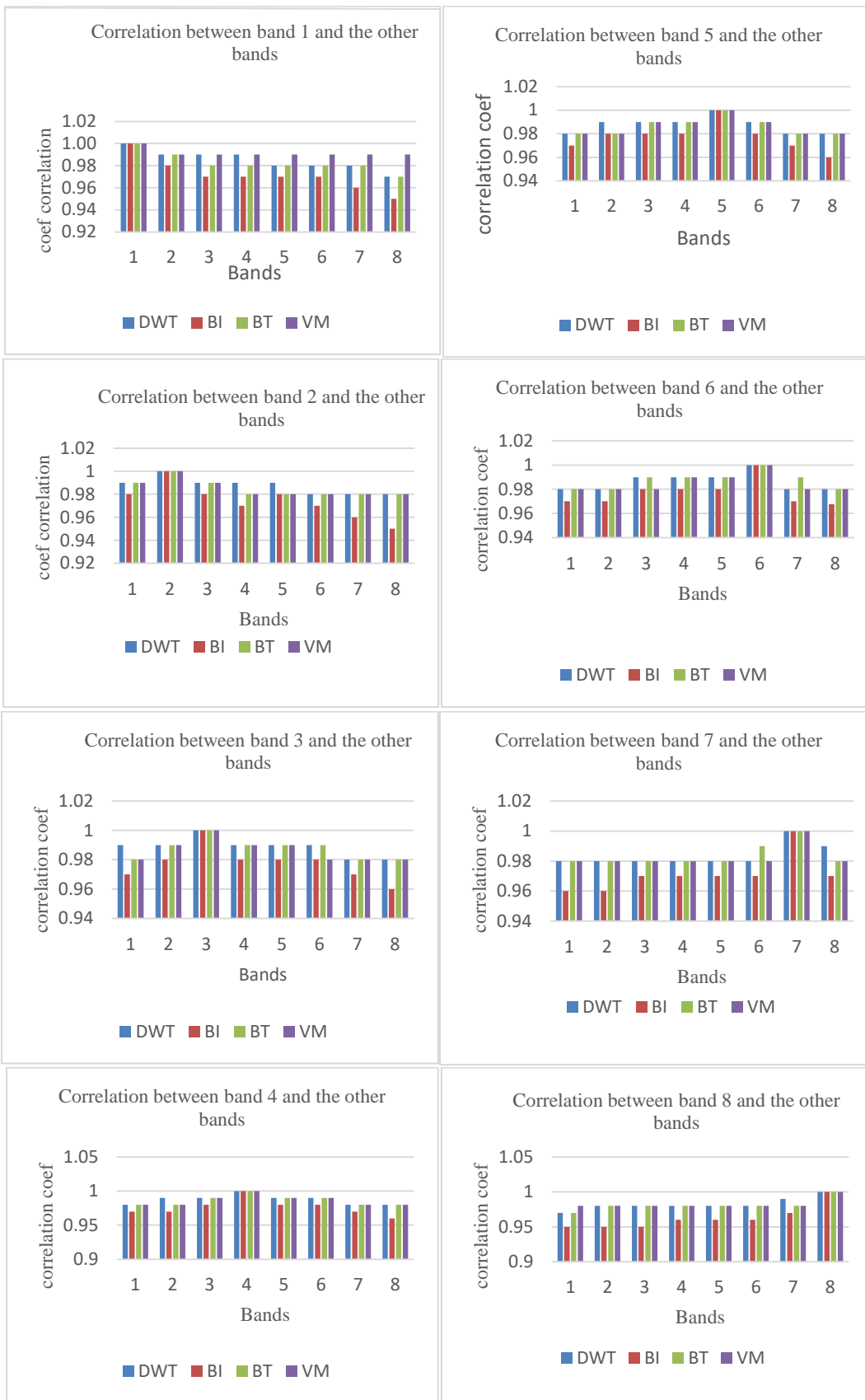
Fig. 7.    Average correlation coefficient between bands by demosaicing methods.

Analysis of the results in Table II shows that the accuracies obtained vary between 80% and 100%. Images demosaiced with bilinear interpolation and binary tree have the best accuracy of 100%. A comparison of the results in Table III shows that the execution time for recognizing demosaiced images varies between two and six sec. Images demosaiced with the binary tree are recognized faster than those of the other methods.

In conclusion, the different results show that the binary tree-based demosaicing method is the best of these four methods in terms of image quality, computational time, and accuracy for facial recognition.

## V. CONCLUSION

We proposed an evaluation of demosaicing methods for facial recognition using MSFA one-shot cameras to identify a suitable demosaicing algorithm in terms of image quality, computation time and decorrelation factor. This study use and compare four demosaicing algorithms on a base of raw images acquired with a MSFA one-shot camera. The binary tree demosaicing method was used to obtain the best quality images with the best computation time and, accuracy for facial recognition. Demosaicing affects the facial recognition system in terms of image quality and time. The better the demosaic images, the better the accuracy of the facial recognition system. The minimum demosaicing time is 12.78 s with bilinear interpolation. This is huge compared to the demosacing time of CFA which is a few milliseconds.

An optimization of this system should be done in our next work to make it real time.

### REFERENCES

[1] R. Lukac and K. N. Plataniotis, "Color filter arrays: design and performance analysis," IEEE Transactions on Consumer Electronics, vol. 51, no. 4, pp. 1260–1267, Nov. 2005, doi: 10.1109/TCE.2005.1561853.

[2] Y.-P. Fan, L. Wei, L. Li, L.Yang, Z-Q HU, Y-H Zheng, and Y-H Wang, "Research on the Modulation Transfer Function Detection Method of a Bayer Filter Color Camera," Sensors, vol. 23, no. 9, Art. no. 9, Jan. 2023, doi: 10.3390/s23094446.

[3] M. Lal, K. Kumar, R. H. Arain, A. Maitlo, S. A. Ruk, and H. Shaikh, "Study of Face Recognition Techniques: A Survey," International Journal of Advanced Computer Science and Applications (IJACSA), vol. 9, no. 6, Art. no. 6, 29 2018, doi: 10.14569/IJACSA.2018.090606.

[4] P. Martins, J. S. Silva, and A. Bernardino, "Multispectral Facial Recognition in the Wild," Sensors, vol. 22, no. 11, Art. no. 11, Jan. 2022, doi: 10.3390/s22114219.

[5] S. Arya, N. Pratap, and K. Bhatia, "Future of Face Recognition: A Review," Procedia Computer Science, vol. 58, pp. 578–585, Jan. 2015, doi: 10.1016/j.procs.2015.08.076.

[6] Y. Monno, S. Kikuchi, M. Tanaka, and M. Okutomi, "A Practical One-Shot Multispectral Imaging System Using a Single Image Sensor," IEEE Transactions on Image Processing, vol. 24, no. 10, pp. 3048–3059, Oct. 2015, doi: 10.1109/TIP.2015.2436342.

[7] P.-J. Lapray, X. Wang, J.-B. Thomas, and P. Gouton, "Multispectral Filter Arrays: Recent Advances and Practical Implementation," Sensors, vol. 14, no. 11, pp. 21626–21659, Nov. 2014, doi: 10.3390/s141121626.

[8] S. Mihoubi, O. Losson, B. Mathon, and L. Macaire, "Multispectral demosaicing using intensity-based spectral correlation," in 2015 International Conference on Image Processing Theory, Tools and Applications (IPTA), Nov. 2015, pp. 461–466. doi: 10.1109/IPTA.2015.7367188.

[9] S. Gutiérrez, A. Wendel, and J. Underwood, "Spectral filter design based on in-field hyperspectral imaging and machine learning for mango ripeness estimation," Computers and Electronics in Agriculture, vol. 164, p. 104890, Sep. 2019, doi: 10.1016/j.compag.2019.104890.

[10] M. Ewerlöf, M. Larsson, and E. G. Salerud, "Spatial and temporal skin blood volume and saturation estimation using a multispectral snapshot imaging camera," in Imaging, Manipulation, and Analysis of Biomolecules, Cells, and Tissues XV, SPIE, Feb. 2017, pp. 105–116. doi: 10.1117/12.2251928.

[11] K. Shinoda, S. Ogawa, Y. Yanagi, M. Hasegawa, S. Kato, M. Ishikawa, Y. Komagata, and N. Kobayashi in 2015 Asia-Pacific Signal and Information Processing Association Annual Summit and Conference (APSIPA), Dec. 2015, pp. 697–703. doi: 10.1109/APSIPA.2015.7415362.

[12] M. E. E. Houssou, A. T. S. Mahama, P. Gouton, and G. Degla, "Robust Facial Recognition System using One Shot Multispectral Filter Array Acquisition System," International Journal of Advanced Computer Science and Applications (IJACSA), vol. 13, no. 1, Art. no. 1, 55/31 2022, doi: 10.14569/IJACSA.2022.0130104.

[13] Porteur UBFC : Gouton, "EXIST (EXtended Image Sensing Technologies),H2020 (ECSEL)," au 12/2018 2015.

[14] S. Mihoubi, O. Losson, B. Mathon, and L. Macaire, "Multispectral demosaicing using intensity-based spectral correlation," in 2015 International Conference on Image Processing Theory, Tools and Applications (IPTA), Nov. 2015, pp. 461–466. doi: 10.1109/IPTA.2015.7367188.

[15] M. Gupta, V. Rathi, and P. Goyal, "Adaptive and Progressive Multispectral Image Demosaicking," IEEE Transactions on Computational Imaging, vol. 8, pp. 69–80, 2022, doi: 10.1109/TCI.2022.3140554.

[16] M. Gupta and P. Goyal, "Demosaicing Method for Multispectral Images Using Derivative Operations," American Journal of Mathematical and Management Sciences, vol. 40, no. 2, pp. 163–176, Apr. 2021, doi: 10.1080/01966324.2021.1939206.

[17] X. Wang, J.-B. Thomas, J. Y. Hardeberg, and P. Gouton, "Discrete wavelet transform based multispectral filter array demosaicking," in 2013 Colour and Visual Computing Symposium (CVCS), Sep. 2013, pp. 1–6. doi: 10.1109/CVCS.2013.6626274.

[18] S. Mihoubi, O. Losson, B. Mathon, and L. Macaire, "Multispectral Demosaicing using Intensity-based Spectral Correlation," presented at the 5th IEEE International Conference on Image Processing Theory, Tools and Applications (IPTA 2015), Nov. 2015, p. 461. doi: 10.1109/IPTA.2015.7367188.

[19] M. Gupta, "Generalizing Spectral Difference Method for Multispectral Image Demosaicking and Analyzing the Role of MSFA Patterns," in 2020 9th International Conference System Modeling and Advancement in Research Trends (SMART), Dec. 2020, pp. 416–420. doi: 10.1109/SMART50582.2020.9337090.

[20] L. Miao, H. Qi, and R. Ramanath, "A Generic Binary Tree-Based Progressive Demosaicking Method for Multispectral Filter Array," in 2006 International Conference on Image Processing, Oct. 2006, pp. 3221–3224. doi: 10.1109/ICIP.2006.312909.

[21] L. Miao, H. Qi, R. Ramanath, and W. E. Snyder, "Binary Tree-based Generic Demosaicking Algorithm for Multispectral Filter Arrays," IEEE Transactions on Image Processing, vol. 15, no. 11, pp. 3550–3558, Nov. 2006, doi: 10.1109/TIP.2006.877476.

[22] L. Miao, H. Qi, and R. Ramanath, "Generic MSFA mosaicking and demosaicking for multispectral cameras," in Digital Photography II, SPIE, Feb. 2006, pp. 88–97. doi: 10.1117/12.642366.

[23] X. Wang, J.-B. Thomas, J. Y. Hardeberg, and P. Gouton, "Median filtering in multispectral filter array demosaicking," in Digital Photography IX, SPIE, Feb. 2013, pp. 103–112. doi: 10.1117/12.2005256.

[24] N. Hounsou, A. T. Sanda Mahama, and P. Gouton, "Extension of luminance component based demosaicking algorithm to 4- and 5-band multispectral images," Array, vol. 12, p. 100088, Dec. 2021, doi: 10.1016/j.array.2021.100088.

[25] J. Driesen and P. Scheunders, "Wavelet-based color filter array demosaicking," in 2004 International Conference on Image Processing,

2004. ICIP '04., Oct. 2004, pp. 3311-3314 Vol. 5. doi: 10.1109/ICIP.2004.1421822.

[26] G. Spampinato, A. Bruna, G. Sanguedolce, E. Ardizzone, and M. L. Cascia, "Improved color interpolation using discrete wavelet transform," in Image and Video Communications and Processing 2005, SPIE, Mar. 2005, pp. 753–760. doi: 10.1117/12.585200.

[27] J. Aelterman, B. Goossens, A. Pižurica, and W. Philips, "Locally adaptive complex wavelet-based demosaicing for color filter array images," in Wavelet Applications in Industrial Processing VI, SPIE, Jan. 2009, pp. 115–126. doi: 10.1117/12.807347.

[28] M. C. Kim, J. H. Park, and M. H. Sunwoo, "Multilevel Feature Extraction Using Wavelet Attention for Deep Joint Demosaicking and Denoising," IEEE Access, vol. 10, pp. 77099–77109, 2022, doi: 10.1109/ACCESS.2022.3192451.

[29] B. K. Gunturk, Y. Altunbasak, and R. Mersereau, "Color plane interpolation using alternating projections," in 2002 IEEE International Conference on Acoustics, Speech, and Signal Processing, May 2002, p. IV-3333-IV–3336. doi: 10.1109/ICASSP.2002.5745367.

[30] M. R. Gupta and T. Chen, "Vector color filter array demosaicing," presented at the Photonics West 2001 - Electronic Imaging, M. M. Blouke, J. Canosa, and N. Sampat, Eds., San Jose, CA, May 2001, p. 374. doi: 10.1117/12.426974.

[31] A. Horé and D. Ziou, "Image Quality Metrics: PSNR vs. SSIM," in 2010 20th International Conference on Pattern Recognition, Aug. 2010, pp. 2366–2369. doi: 10.1109/ICPR.2010.579.

[32] Z. Wang and A. C. Bovik, "Reduced- and No-Reference Image Quality Assessment," IEEE Signal Processing Magazine, vol. 28, no. 6, pp. 29–40, Nov. 2011, doi: 10.1109/MSP.2011.942471.

[33] M. Siniukov, D. Kulikov, and D. Vatolin, "Applicability limitations of differentiable full-reference image-quality metrics," in 2023 Data Compression Conference (DCC), Mar. 2023, pp. 1–1. doi: 10.1109/DCC55655.2023.00082.

[34] A. Mittal, R. Soundararajan, and A. C. Bovik, "Making a 'Completely Blind' Image Quality Analyzer," IEEE Signal Processing Letters, vol. 20, no. 3, pp. 209–212, Mar. 2013, doi: 10.1109/LSP.2012.2227726.

[35] C. Kwan, B. Chou, and J. F. Bell III, "Comparison of Deep Learning and Conventional Demosaicing Algorithms for Mastcam Images," Electronics, vol. 8, no. 3, Art. no. 3, Mar. 2019, doi: 10.3390/electronics8030308.

[36] A. G. Asuero, A. Sayago, and A. G. González, "The Correlation Coefficient: An Overview," Critical Reviews in Analytical Chemistry, vol. 36, no. 1, pp. 41–59, Jan. 2006, doi: 10.1080/10408340500526766.

[37] K. Simonyan and A. Zisserman, "Very Deep Convolutional Networks for Large-Scale Image Recognition," arXiv:1409.1556 [cs], Apr. 2015, Accessed: Oct. 13, 2021. [Online]. Available: http://arxiv.org/abs/1409.1556

# An Artificial Intelligence Method for Automatic Assessment of Fuzzy Semantics in English Literature

Meiyan LI

Faculty of International Studies
Henan Normal University
Henan 453007, China

*Abstract*—This Online writing and evaluation are becoming increasingly popular, as is automatic literature assessment. The most popular way is to obtain a good evaluation of the essay and article is by the automatic scoring model. However, assessing fuzzy semantics contained in reports and papers takes much work. An automated essay and articles assessment model using the long-short-term memory (LSTM) neural network is developed and validated to obtain an appropriate assessment. The relevant theoretical basis of the recurrent neural network is introduced first, and the quadratic weighted kappa (QWK) elevation method is cited here to develop the model. The LSTM network is then awarded for developing the general automatic assessment model. The available model is modified to get better performance by adding a convolutional layer(s). Finally, a data set of 7000 essays is segmented based on the ratio of 6:2:2 to train, validate, and test the model. The results indicate that the LSTM network can effectively capture the general properties of the essay and articles. After adding the convolutional layer(s), the LSTM+convolutional layer(s) model can get better performance. The QWK values are higher than 0.6 and have an improvement of 0.097 to 0.134 compared with the LSTM network, which proves that the results of the LSTM network combined with the convolutional layer(s) model are overall satisfactory, and the modified model has practical values.

*Keywords—Automatic assessment; recurrent neural networks; long short-term memory (LSTM); quadratic weighted kappa (QWK); convolutional layer*

## I. INTRODUCTION

In the traditional literature evaluation scene, the teacher or organizer designs the tasks, the candidates answer, and the teacher or organizer finally assesses the quality of the candidates' products by scoring. The most tedious part of the whole process is the manual evaluation and marking. It brings a heavy workload to evaluators and is prone to correction errors and long evaluation cycles, negatively impacting assessing. As computer technology and artificial intelligence develop, the automatic identification technology of filling multiple-choice questions in answer sheets has been widely used. The main task of assessment, involving complex processes such as handwritten digit detection, recognition and understanding, still relies on manual correction, especially in literature review and evaluation with fuzzy semantics. The candidates' handwritten text and the printed text of the paper are distributed in the same picture. When assessing, it is necessary to make an accurate distinction. At the same time, it is essential to detect the type of question to which the text belongs so that different correction strategies can be used

according to various tasks. In addition, the handwriting of other candidates is different, and the readers are either compact or sparse, which makes text detection and recognition face greater challenges [1,2]. With the enrichment of computing and data resources and the innovation of various network structures, deep learning has performed well in various tasks, and therefore, artificial intelligence has gradually been widely used in images and text detection [3, 4]. The key technologies required to realize intelligent marking technology, including handwritten character detection, recognition, etc., are also very popular research fields. Recently, many relatively advanced research results have been reported, which makes it possible to achieve comprehensive intelligent evaluation [5, 6].

The continuous development of artificial intelligence and computer performance significantly improved the accuracy and efficiency of automatic essay and article evaluating and scoring models. Also, the development of neural networks has promoted the achievements of natural language processing technology in some related fields. It has brought new research directions to the automatic essay and articles evaluating and scoring research [7, 8]. The most typical is Automated Student Assessment Prize (ASAP) essay-scoring competition organized by Kaggle in 2012, and the appearance of the ASAP made public datasets available for many research efforts. Based on this dataset, researchers in different countries have conducted related research on essays and articles evaluating and scoring tasks. For instance, Alikaniotis D et al. (2016) [9] built a model modified from LSTM by citing the ASAP data set. Then they used this model for t automatic evaluation and scored essays and articles. Similarly, using the ASAP data set, Kaveh et al. developed a model on the basis of recurrent neural networks and tried to use this model to learn the consistency between an essay and articles and real scores [10]. The results show that this method improved the model's ability to understand and capture the essay's main information and reports. Farag Y et al. also developed an automated easy evaluating and scoring model using the ASAP data set and the com. Theetween, a series of baselines and model outcomes, demonstrates its ability on the Automated Essay Scoring (AES) task and the flagging adversarial input, strengthening the effectiveness of neural essay and articles evaluating and scoring models [11]. These significant explorations kicked off the prelude of neural networks for automatic essays and papers evaluating and scoring.

Meanwhile, the successful application of large-scale pre-trained language models has brought breakthroughs to many

natural language processing tasks as well. For instance, Rodriguez et al. compared the BERT and XLNet model based on natural language processing (NLP) neural networks adopted to achieve a high-quality Kaggle AES dataset. The results show that BERT and XLNet can produce more accurate outcomes than manual results and save time and money in grading essays and articles [12]. Mayfield and Black used the pre-trained language model BERT to solve the problem of automatic writing, paperless evaluating and scoring and their experiment. They showed that BERT achieved good results in the automated English essay and articles evaluating and scoring task, indicating that BERT is theoretically and practically feasible to solve the automatic grading of English papers and reports [13]. From the system structure level, it can be seen that using software algorithms to extract the information feature values of standard files is the foundation for achieving accurate translation in non-semantic environments. The similarity between words and sentences is a factor that causes the system to decline in translation in different semantic environments. The relative degree of a sentence includes multiple aspects such as part of speech, syntax, and sentence structure. By calculating sentence similarity, the degree of differentiation of sentences can be found. The larger the similarity value, the more information about word form, syntax, and semantics between the two sentences is resolved.

Through the analysis of the current research about automated essays and article evaluating and scoring, the development of automated essay and article evaluating and scoring technology can be divided into three periods [14,15]. The first period is the artificial feature extraction period. The typical feature of this period is determining which parts of the essay and articles to extract manually and building a regression model based on these features by machine learning-based methods [16]. The advantage of this method is that it can be logically explained. The disadvantage of this method is also obvious. Due to many relevant features that need to be extracted by humans, it is challenging to reconstruct a large number of data sets. At the same time, these features may not directly reflect the deep fuzzy semantics of the essay and articles. The second period is the neural network period. In this period, word vectors are used to build models. Word vectors are developed by learning text information from essays. The main advantage is that it only needs manual feature extraction work. The disadvantage is that the model is not open and transparent since the model's training process is carried out in a black box. The third period is the transfer learning period [17, 18]. In this period, the knowledge learned from a large amount of corpus using the pre-trained language model is transferred to the automatic evaluating and scoring task, which can effectively avoid training the model from the beginning and achieves good results with relatively small datasets.

The application of distributed ultra-large computing power computers and the advent of large-scale data sets jointly promote the further development of neural networks in the field of automatic evaluating and scoring of essays and articles and make the automated essay and articles and articles evaluating and scoring evolve into the third stage as described above. Although the LSTM network is more efficient than the standard recurrent neural network and can effectively improve the model learning ability, capture the features and provide generally acceptable results to some extent. Still, it may not work well when meeting with fuzzy semantics contained in literature. Therefore, in this work, the main model modified from LSTM networks is developed and improved by adding convolutional neural network layers since the introduction of a convolutional neural network layer into the evaluating and scoring model can strengthen the ability of the model to capture local information in the essay and articles. Then the effectiveness of the LSTM networks combined with convolutional neural network layers is evaluated with a relatively large database.

In the process of English translation, the more similar the semantics are, the greater the correlation, which can easily lead to comprehension errors in different contexts and bring difficulties to translation work. Based on this, a similarity calculation model based on a combination of semantic dictionaries and corpora is established, starting from bilingual materials of English and Chinese sentences. Under the conditions of the established corpus, relevant semantic extraction rules and dependencies are determined. Through the English sentence similarity algorithm and the vector space model standard, the calculated similarity is used as a vector element to find the degree of differentiation in sentences, distinguishing between sentences and words in terms of part of speech, syntax, and tense. The research results indicate that the system has high accuracy and recall rate in sentence translation, especially in the English translation process of prepositions, function words, and tenses, with higher translation efficiency and accuracy. Evaluating the fuzzy semantics contained in reports and papers requires a lot of work. This article develops and validates an automated paper evaluation model using Long Short Term Memory (LSTM) neural networks to obtain appropriate evaluations.

This article evaluates the innovation contribution as follows:

*1)* Developed and validated an automated paper evaluation model using Long Short Term Memory (LSTM) neural networks to obtain appropriate evaluations. By adding convolutional layers, modifications were made to the available models to achieve better performance.

*2)* Traditional RNNs are prone to gradient vanishing when dealing with long sequences, making it difficult to train. LSTM introduces a gating mechanism, which can effectively alleviate the problem of gradient vanishing and process longer sequence data.

*3)* LSTM can better capture long-term dependencies in sequence data through cell state and gating mechanisms.

## II. THEORETICAL BASIS OF RECURRENT NEURAL NETWORK

### A. Recurrent Neural Network

Recurrent Neural Networks (RNNs) are mainly used to deal with timing problems. There is a connection between different neuron states in the RNN hidden layer. The input in the neuron state includes the input layer and consists of the outcomes of the previous neuron state. The semantic information before and

after the text sequence is very important to the recognition accuracy of the current series, so RNN is mostly used in text recognition, speech recognition and other tasks. RNNs are also used in artificial intelligence and machine learning. In the development of the automatic essay and articles evaluating and scoring model, essay and articles text is regarded as sequence data because the text information contains contextual semantic information. RNNs have advantages in processing data, and RNNs have advantages in processing textual information because RNNs can memorize previously learned content [19].
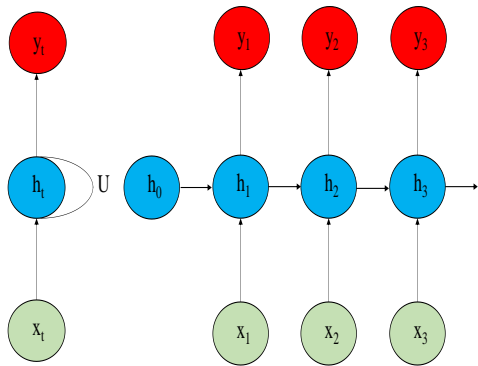


(a) General structure of RNNs    (b) Expended structures of RNNs

Fig. 1.    The model structure of the recurrent neural network.

Text information is generally input with unequal lengths, but the word length of each text is different. At the same time, understanding the text information needs to consider the order of words; that is, words are input individually. The recurrent neural network can also accept sequence data with an unequal length not defined in advance [20]. The performance of RNNs is affected by the knowledge learned in the past, which means that the processing output may obtain the features of previously known knowledge. Remembering the features learned from the previous knowledge through the vector representation of the hidden layer, the RNNs model can generate one or more output vectors from one or more input vectors and generate different outputs even with the same input. The recurrent neural network model's structural characteristics are shown in Fig. 1(a).

The figure above depicts the properties of the recurrent neural network at sequence number t. W, U, and V correspond to the weights of the input layer $x_t$ passed to the hidden layer $h_t$, between the hidden layers, and from the hidden layer $h_t$ to the output layer $y_t$, respectively. As can be seen from Fig. 1(b), an important feature of RNNs is parameter sharing, and the meanings of parameters are:

*1)* $x_t$ is the input of the training sample, and $t$ is the sequence number;

*2)* $h_t$ is the hidden state of the model, and it is computed by $x_t$ and $h_{t-1}$;

*3)* $y_t$ is the model's output, which is determined by the $h_t$ at the current hidden state.

The RNNs equation is expressed as follows:

$$y_t = g(Vh_t) \qquad (1)$$

$$h_t = f(Wx_t + Uh_{t-1}) \qquad (2)$$

RNNs can memorize knowledge, but they need help remembering long text information. This is because when ordinary RNNs deal with long sequence problems, passing the gradient from the back of the sequence to the front line through the back-propagation algorithm is difficult. In recent decades, many versions have been developed and built with the research progress of the recurrent neural network, among which the LSTM network is the most successful. This is because the LSTM network solves the long-term dependence problem in the training process.

*B. LSTM Network*

During the predicting process, the recognized text could be infinite because of the variety of the length of the text sequence. Suppose the position of the currently predicted text or the text whose semantic information is consistent with the text is large. In that case, the ordinary recurrent neural network will lose part of its semantic information, thereby reducing the accuracy of prediction results. The network of LSTM is a more advanced version of RNNs and solves this problem very well. The setting of the gate structure prevents the LSTM model from retaining all the information indiscriminately, like the RNN model. It cannot highlight the key points which solve the problem of gradient disappearance in the learning process of the model [21]. The main difference between LSTM and ordinary recurrent neural networks is that LSTM has three gates: the forgotten, input, and output. The model can remind the information of each previous neuron, reducing the loss of information in the transmission process. Therefore, the LSTM model can efficiently retain important data according to the task objective and uses the information judgment as to the parameter of model learning, which greatly increases the learning efficiency of the model [22].

At the same time, LSTM can also solve the problem of gradient descent and thus is widely used in sequence data tasks, such as language understanding, segmentation, and translation. It has been verified in many experiments that LSTM is more effective than standard RNNs, which can effectively improve the model learning ability. Due to the careful design of LSTM, introducing the gating mechanism can alleviate the gradient disappearance of the recurrent neural network, thereby memorizing long text information. The LSTM consists of five different parts [23, 24]:

*1)* Unit state: The internal memory of the LSTM unit.

*2)* Hidden state: This state is used to calculate the prediction result of the model.

*3)* Input gate: It is used to judge the amount of inputted information that can be sent to the unit state.

*4)* Forget gate: It is used to judge the number of previous unit states that can be sent to the current unit state.

*5)* Output gate: It judges how many unit states can be sent to the hidden state.

In a recurrent neural network model, the unit's state changes with each input in the current form. This directly leads to the fact that in the cyclic neural network structure, the team's state is always changing, and this mechanism causes the cyclic neural network to not store long-term dependencies well. In LSTM, the current cell state relies not only on the input of

the current state but also that of at previous step. Therefore, the LSTM can decide to update at a certain moment or forget the internal information stored in each neuron in the cell state. Namely, the LSTM has a mechanism to keep the cell state unchanged so that the LSTM can store long-term dependencies. The data flow diagram in LSTM is shown in Fig. 2.
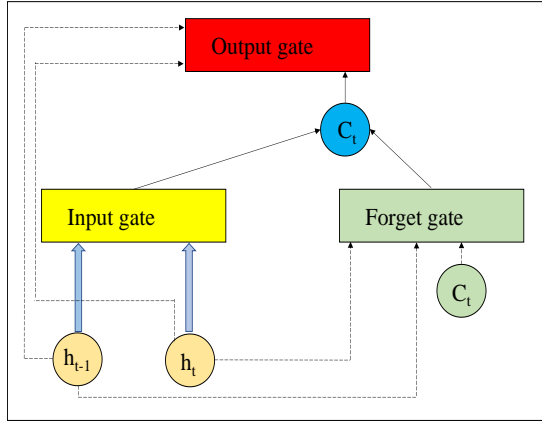


Fig. 2. The data flow diagram in LSTM.

As shown in Fig. 2, LSTM mainly introduces the gating unit concept to control the unit's state. LSTMs have gates for each operation a cell needs to perform. Each gating team takes a continuous value ranging from 0 to 1, where 0 indicates that all the information is blocked and will not be passed to the next step, and 1 means that all information is passed to the next gate. LSTM network uses such gating units for each neuron in the team. The calculation equation of each gate control unit is described below. The calculation equation for the input gate is shown in the following equations.

$$i_t = a(w[h_{t-1}, x_t]^T + b_i) \quad (3)$$

$$\tilde{c}_t = tanh(\psi_{cyt}) - tanh(w_c[h_{t-1}]^T + b_c) \quad (4)$$

where, $i_t$ = represents the information amount of the input state saved to the unit state, and $\tilde{c}_t$ means the information after the Unit State is updated. *A* is defined as an activation function, the weight matrices are $\omega$, and $\omega_c$ and the bias matrices are $b_i$ and $b_c$. The revised equation for the current cell state is shown in Eq. (5).

$$c_t = f_t c_{t-1} + i_t \tilde{c}_t \quad (5)$$

In the equation, $c_t$ represents the information currently saved by the unit state, and $c_{t-1}$ is the information held by the unit state at the previous moment. The calculation equation of the forgetting gate is shown in Eq. (6).

$$f_t = a(w_f[h_{t-1}, x_t]^T + b_f) \quad (6)$$

where, $f_t$ indicates the forget gate at time $t$. The forget gate controls whether the information can be transmitted to the current moment. Calculate $f_t$ is calculated in the matrix formed by the output state of the hidden layer $h_{t-1}$ and the current input state $x_t$ at the previous input, multiply it with the weight matrix $\omega_f$, and finally, add the bias matrix $b_f$. The calculation equation of the output gate is shown in Eq. (7) and Eq. (8).

$$f_t = a(w_0[h_{t-1}, x_t]^T + b_0) \quad (7)$$

$$h_t = u_t \, tanh(c_t) \quad (8)$$

In the equations, $u_t$ is the updated output information of the storage unit, $h_t$ is the output information of the hidden layer at the current moment, $w_o$ is the weight used to calculate the forgotten team, and $b_o$ is the bias matrix.

## III. MODEL CONSTRUCTION AND EXPERIMENTAL SETUP

Based above research, the automatic evaluating and scoring model established is developed. The main model structure of the proposed model can be briefly described by following steps: first, the text in the corpus is segmented, and then the word segmentation result is used to construct a word vector, and the word vector work as the input of the LSTM evaluating and scoring model. At the same time, a convolutional layer is added before the LSTM layer. This can improve the prediction of the LSTM method because the convolutional layer can effectively understand the text's local information and fuzzy semantics.

### A. LSTM-based Essay and Articles Automatic Evaluating and Scoring Model

Since the essay and article text contains contextual knowledge, it can be regarded as sequence information. The model-building process is shown in Fig. 3. Because the long short-term memory network cannot directly take text as input, the next step is to convert the essay and article text into word vectors after the intake of the corpus. Then the obtained word vectors will be passed to the neural network model for prediction, optimize the model through the optimizer, and finally build, the model.

The Adam optimizer is used in this experiment. In the model optimization, the mean squared error (MSE) loss function is selected to make the neural network model better optimized, which is shown in Eq. (9).

$$MSE = \frac{1}{n}\sum_{i=1}^{n}(y_i - \bar{y}_t)^2 \quad (9)$$
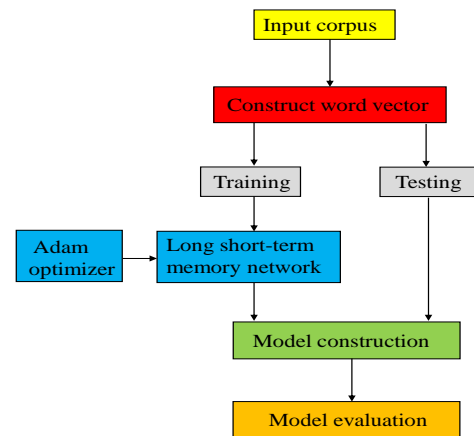


Fig. 3. The model-building process.

### B. Evaluation Method

The QWK coefficient is generally used as an evaluation index in the automatic grading of related essays and articles. It

can well reflect the consistency between the predicted quality index (mostly in the form of score) and the actual quality index of the essay and articles [25] and improves the validity of the evaluation results. The QWK coefficient introduces a penalty mechanism based on the KAPPA coefficient. If the error between the composition's predicted quality index and the composition's actual quality index is larger, the QWK coefficient will be smaller. The penalty mechanism enables the QWK coefficient to reflect the consistency between the quality index predicted by the proposed model and the manual quality index of the essay and articles. Although some algorithms have good performance in certain datasets, they may encounter difficulties in other datasets. In addition, by adjusting the hyperparameters of the algorithm that controls the training process, performance can be improved. The performance of models in machine learning problems largely depends on the dataset and training algorithms. Choosing the correct training algorithm can change the story of the model. Nowadays, an adaptive machine learning algorithm is used for different biological, biomedical, and natural categories [26].

The fuzzy semantic of English literature is a two-sided existence, such as some ambiguous expressions. And due to the differences between cultures, clearer semantic content can result in differences in understanding. The QWK coefficient uses a weighting method to strengthen the result. If the excessive deviation between the model prediction and real quality index, it would penalise the extreme difference by reducing the QWK coefficient. Using the QWK coefficient can not only measure the consistency of the evaluating and scoring model but also improve the recognition accuracy of fuzzy semantic contents in English literature. The equation for calculating the QWK coefficient is shown in Eq. (11). But the first step is to construct the weight matrix, and the calculation equation of the weight matrix is shown in Eq. (10).

$$W_{i,j} = \frac{(i-j)^2}{(n-1)^2} \qquad (10)$$

In the equation, $i$ and $j$ is the quality index given by the experts (real quality index) and essay and articles evaluating and scoring models, respectively. N indicates 9, the number of essays and articles database. After building the weight matrix, the matrix $N$ and the prediction matrix $E$ are built. $N_{i,j}$ is the amount samples with real rating $i$ and model rating $j$. $E$ is the outer product of the real marks and the model quality index vector. The QWK coefficients are calculated using the constructed $E$ matrix and $N$ matrix.

$$k = 1 - \frac{\sum_{i,j}(W_{i,j}N_{i,j})}{\sum_{i,j}(W_{i,j}E_{i,j})} \qquad (11)$$

Evaluators give the essay and article quality index used in this paper, and the essay and articles' real quality index are regarded as a true index of essay and article quality. So, the evaluation of the evaluating and scoring model built in this paper is transformed into the consistency problem between the model results and the real marks. In this paper, the QWK coefficient is used as the measurement method to test the consistency since the QWK coefficient can reflect the model prediction quality index, which can reflect the capability of assessing the English literature with fuzzy semantics. The meaning of the QWK coefficient is shown in Table I.

TABLE I. THE MEANING OF QWK

| QWK | Consistency strength |
|---|---|
| <0.20 | Poor |
| 0.21~0.40 | General |
| 0.41~0.60 | Medium |
| 0.61~0.80 | Good |
| 0.81~1.00 | Best |

This article collects a set of paper data, including papers from various disciplines. Firstly, we use a portion of the dataset for training, and then test the remaining dataset. Table II shows the performance of our model on the test set.

TABLE II. PERFORMANCE INDICATORS OF THE MODEL ON THE TEST SET

| Accuracy | 0.85 |
|---|---|
| Precision | 0.83 |
| Recall | 0.82 |
| F1 Score | 0.80 |

## IV. EXPERIMENT AND RESULT ANALYSIS

### A. Test Setup

*1) Normalization and inverse normalization*: The output of the proposed model is the predicted essay and article quality index. If the input essay and article quality index are in a different grade range, it may impact the model's outcomes.

In most situations, the quality index of essays and articles by scoring can be divided into three categories: the first is 40-95, the second is 65-95, and the third is 50- 95 points. Due to the different range of scores, the normalization of essay and articles scores is firstly performed to get a uniform index, and the core idea of normalization is to map essay and articles scores from different score segments to floating-point numbers between (0, 1), which is more conducive to processing of the model. The normalized calculation equation is shown in Eq. (12).

$$x' = \frac{x - x_{Min}}{x_{Max} - x_{min}} \qquad (12)$$

In Eq. (12), $x$ represents the real essay and articles score, $M_{in}$ and $M_{ax}$ represent the lowest and highest score of the scoring range, and $x'$ represents the normalized result obtained by normalizing the real essay and articles score.

Before inputting into the model, the essay and article scores in the corpus are first normalized. Then the corpus is divided into a training set, validation set, and test set according to the ratio of 6:2:2. In the model's training process; the normalized score will be used as the label. After the training process is completed, the essay and articles in the test set are used as the input, and the trained model is then used to predict the score of the essay and articles. However, the score obtained at this state is not (0-100) but the normalized predicted score. In order to calculate the QWK coefficient between the real score results and the model prediction results, we need to perform inverse normalization on the normalized prediction scores. The inverse normalization calculation equation is shown in Eq. (13).

$$y = y'(xmin_{max} + x_{min}) \qquad (13)$$

In Eq. (13), $y$ represents the normalization result predicted by the model, and $x_{min}$ and $x_{max}$ represent the lowest and highest scores in the real scoring range. After performing the inverse normalization operation, the prediction score of the model can be obtained.

*2) Experimental arrangement and hyperparameter settings*: During the experiment, 7000 essays and articles corpus from the Kaggle dataset were cited and divided into the training set, validation set, and test set with the ratio of 6:2:2. To train the LSTM model on the training set, different numbers of hidden layers were used to observe the effect of other numbers of hidden layers on the results of the model $b_v$. The LSTM network structure used is shown in Fig. 4.
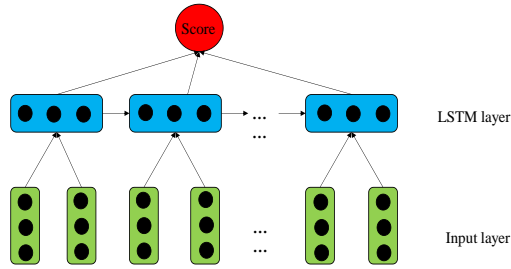


Fig. 4.    The LSTM network structure.
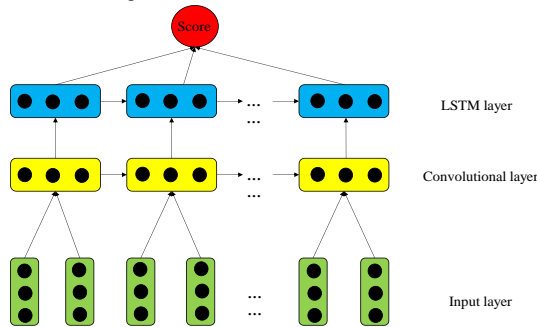


Fig. 5.    The LSTM+ convolutional layer.

At the same time, in the research of Taghipour K et al [10]., it was found that adding a convolutional layer before the recurrent neural network can effectively improve the model's capability of capturing the local information of the text. Therefore, based on the above experiments, adding a convolutional layer before the LSTM layer is embedded and observing whether the additional convolutional layer(s) can improve the model's performance is proposed. The network structure of the LSTM+convolutional layer used in this study is shown in Fig. 5.

Simulation experiments determine the model's hyperparameters after building the LSTM model. The parameters are shown in Table III.

TABLE III.    THE VALUES OF MODEL PARAMETERS

| Parameters | Values |
| --- | --- |
| Learning rate | 0.001 |
| Batch size | 64 |
| Regular optimization | 0.5 |
| Activation function | ReLU |
| Number of iterations | 30 |

### B. Results and Analysis

Based on completing the model construction in the previous section, the number of hidden layers of the network to 1, 5, and 9 layers are built. The QWK results obtained by the LSTM network model are shown in Fig. 6.

Fig. 6 shows that the QWK coefficient of the experimental results obtained by the essay and articles evaluating and scoring model constructed based on the LSTM network is at a moderate level of consistency, according to Table I. The value of QWK ranges from 0.17 to 0.59, which indicates that the accuracy of the LSTM is not satisfactory, as shown in Fig. 6(a). Increasing the number of hidden layers, the model's performance also increases. When the hidden layers are 5 and 9, the value of QWK are 0.31~0.57 and 0.38~0.59, respectively. The average weight of QWK also increases from 0.464 to 0.499 and 0.515 when hidden layers are increased from 1 to 5 and 9. It indicates that as the depth of the LSTM network grows, the model has better nonlinear expression ability and can perform more complex transformations. The experimental results show that deepening the network depth can effectively improve the output results.



(a). 1 hidden layer



(b). 5 hidden layers
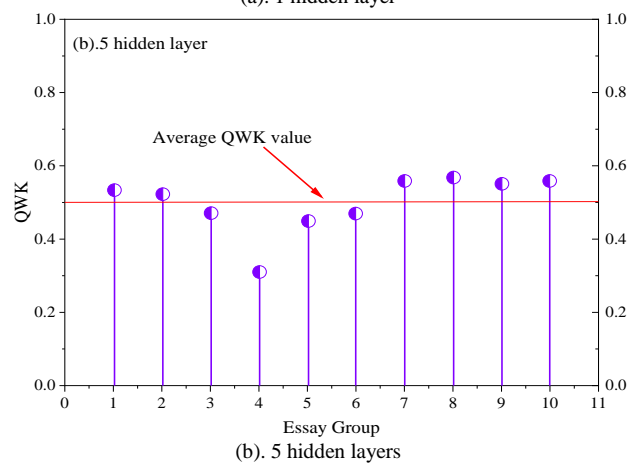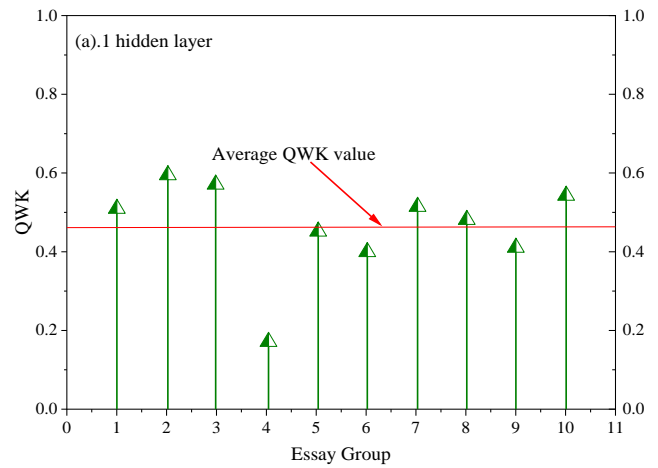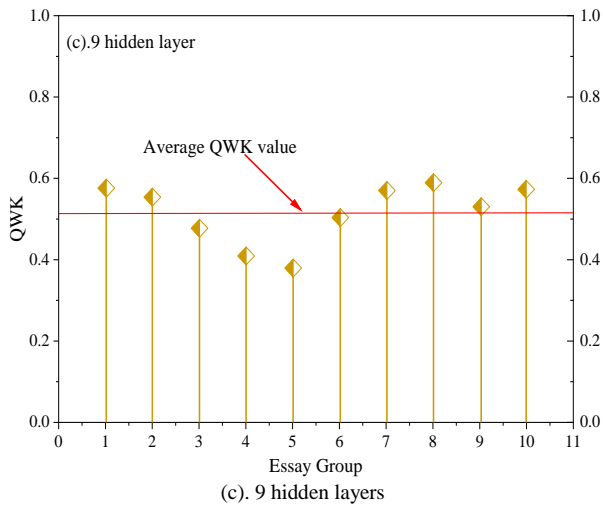
Fig. 6.    The QWK values obtained by the LSTM network model.

The convolutional layer is added to conduct a comparative neural network experiment based on the above experimental results. The addition of the convolutional layer is to improve the ability to capture the local text information. The QWK results obtained by adding the convolutional neural layer into the Long-Short-Term Memory Network model are shown in Fig. 7.



(a). 1 hidden layer



(b). 5 hidden layers
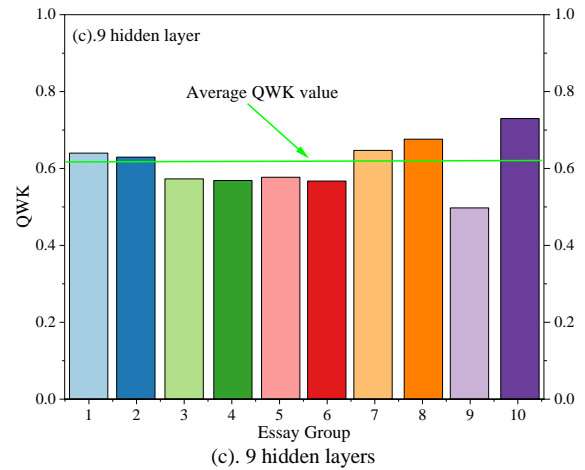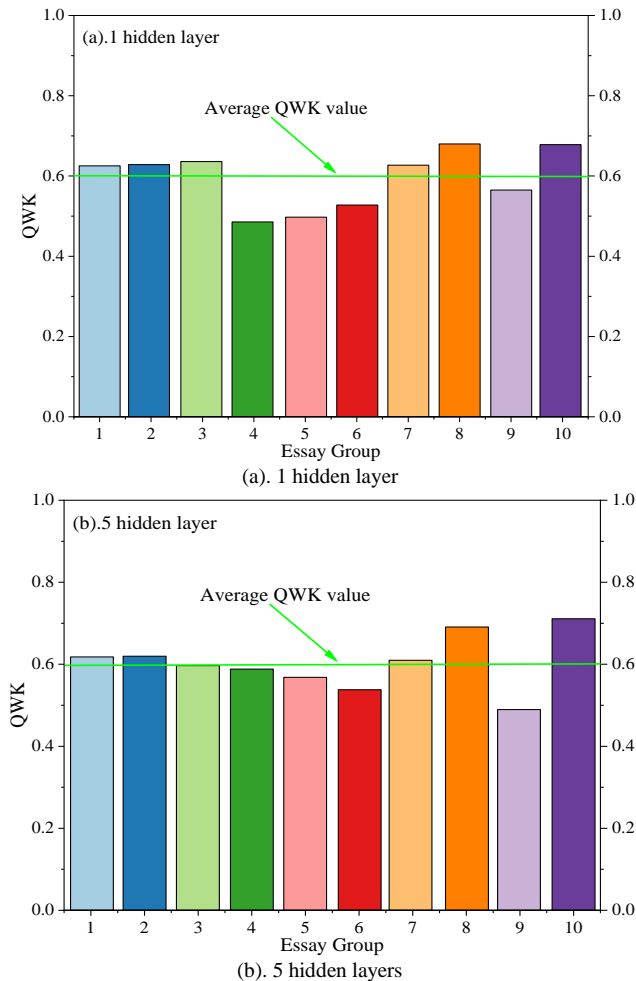


Fig. 7.    The QWK results after adding the convolutional neural layer.

It can be seen from Fig. 7 that using the essay and articles evaluating and scoring the model constructed based on the LSTM network, adding the cumulative neural network layer has significantly improved the experimental results of the model. However, the QWK coefficient could be at a better level of consistency. After LSTM is incorporated with the convolutional neural layer, the value of QWK in 1, 5 and 9 layers are 0.41~0.68, 0.49~0.69 and 0.5~0.68, respectively. The average values of QWK are at a good level of consistency with values of 0.598, 0.604 and 0.612. This experimental result confirms that adding the convolutional layer can capture the local information of the text.

From Fig. 6 and Fig. 7, it is clear that the Long-Short-Term Memory Network model can provide an acceptable experimental result using the QWK coefficient in the evaluation process. Compared Fig. 6 with Fig. 7, adding the convolutional layer(s) can increase the accuracy of the proposed model. By comparing the average QWK values of LSTM and LSTM+ convolutional layer, it can be observed that the QWK values are improved (the improvement is 0.097~0.134), as shown in Fig. 8, indicating that the neural network with the convolutional layer(s) can perform more complex feature learning, and the network has better representation ability. Based on TableI, the LSTM+C can obtain good results and has practical values.
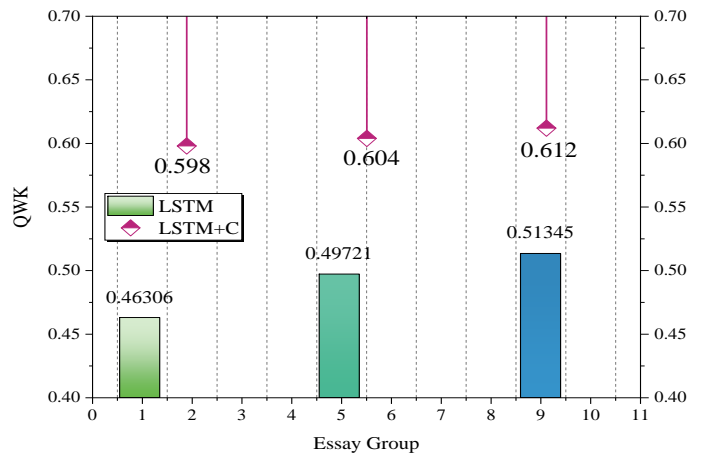


Fig. 8.    The comparison of LSTM and LSTM+ convolutional neural layer.

The research results indicate that using papers and articles to evaluate and grade models constructed based on LSTM networks. This not only increases the cumulative neural network layer, but also significantly improves the experimental results of the model. The calculation for LSTM is feasible. Approximate calculation methods and other dependency methods can be used to accelerate the training process. For example, techniques such as truncation or compression can be used to reduce the number of parameters and calculate Type 2 simplification: in order to solve the problem of STM interpretation. A simpler model can be used, which has fewer parameters and mechanisms than LSTM, but still handles sequence numbers well. If the number of training is insufficient, it is possible to use the number of strong techniques to generate more books, or use transfer learning to utilize data from other tasks to improve model performance.

## V. Conclusion

In this paper, the model construction process and related experimental settings are introduced，and the automatic essay and articles assessment model modified from the neural network is developed and validated in assessing English literature with fuzzy semantics. After comparing the results of the prediction, the following conclusions are drawn:

First, in developing the the model, the QWK elevation method is cited due to its consistency evaluation properties that that can improve the recognition of fuzzy semantics content. And then, the long-short-term memory network is modified by adding the convolutional layer(s) into the LSTM model.

Then, 7000 articles were segmented based on the ratio of 6:2:2 to train, validate, and test the proposed model. The comparison and analysis of experimental results indicate that LSTM can generally capture the real features of the articles. After adding the convolutional layer(s), the proposed model can get better performance by improving 0.097 to 0.134 of the QWK value. These results prove that the automatic essay and articles evaluating and scoring model based on neural network+ convolutional layer(s) can evaluate the English literatures containing fuzzy semantics.

However, an important advantage of neural networks is that they can learn complex patterns from a large amount of data. However, one limitation of this method is that it usually only captures the surface features of the data and may not be able to deeply understand the true meaning of the text. For English literature, this issue may be more severe due to the inherent ambiguity and ambiguity in language. Although English has relatively fixed grammar and vocabulary, the same word or phrase may have completely different meanings in different contexts, and this meaning usually requires in-depth contextual understanding to accurately grasp. Future research can focus on developing more effective models, such as combining natural language processing (NLP) technology and deep learning technology, to improve the model's ability to understand semantics while reducing reliance on a large amount of high-quality data.

## References

[1] Yannakoudakis H, Andersen ØE, Geranpayeh A, Briscoe T, Nicholls D. Developing an automated writing placement system for ESL learners. Applied Measurement in Education. 2018;31:251–67.

[2] Beseiso M, Alzubi OA, Rashaideh H. A novel automated essay scoring approach for reliable higher educational assessments. J Comput High Educ. 2021;33:727–46.

[3] Moreno A, Redondo T. Text analytics: the convergence of big data and artificial intelligence. IJIMAI. 2016;3:57–64.

[4] Lee Y-J, Park J-Y. Identification of future signal based on the quantitative and qualitative text mining: a case study on ethical issues in artificial intelligence. Qual Quant. 2018;52:653–67.

[5] Ramesh D, Sanampudi SK. An automated essay scoring systems: a ystematic literature review. Artif Intell Rev. 2022;55:2495–527.

[6] 6. Yang L, Liu W. Design of English intelligent simulated paper marking system. Complexity. 2021;2021:1–10.

[7] Dong F, Zhang Y, Yang J. Attention-based recurrent convolutional neural network for automatic essay scoring. Proceedings of the 21st conference on computational natural language learning (CoNLL 2017). 2017. p. 153–62.

[8] Uto M, Okano M. Robust neural automated essay scoring using item response theory. Artificial Intelligence in Education: 21st International Conference, AIED 2020, Ifrane, Morocco, July 6–10, 2020, Proceedings, Part I 21. Springer; 2020. p. 549–61.

[9] Alikaniotis D, Yannakoudakis H, Rei M. Automatic text scoring using neural networks. arXiv preprint arXiv:160604289. 2016;

[10] Taghipour K, Ng HT. A neural approach to automated essay scoring. Proceedings of the 2016 conference on empirical methods in natural language processing. 2016. p. 1882–91.

[11] Farag Y, Yannakoudakis H, Briscoe T. Neural automated essay scoring and coherence modeling for adversarially crafted input. arXiv preprint arXiv:180406898. 2018;

[12] Rodriguez PU, Jafari A, Ormerod CM. Language models and automated essay scoring. arXiv preprint arXiv:190909482. 2019;

[13] Mayfield E, Black AW. Should you fine-tune BERT for automated essay scoring? Proceedings of the Fifteenth Workshop on Innovative Use of NLP for Building Educational Applications. 2020. p. 151–62.

[14] Ke Z, Ng V. Automated Essay Scoring: A Survey of the State of the Art. IJCAI. 2019. p. 6300–8.

[15] Hussein MA, Hassan H, Nassef M. Automated language essay scoring systems: A literature review. PeerJ Comput Sci. 2019;5:e208.

[16] Uto M. A review of deep-neural automated essay scoring models. Behaviormetrika. 2021;48:459–84.

[17] Lagakis P, Demetriadis S. Automated essay scoring: A review of the field. 2021 International Conference on Computer, Information and Telecommunication Systems (CITS). IEEE; 2021. p. 1–6.

[18] Madnani N, Cahill A. Automated scoring: Beyond natural language processing. Proceedings of the 27th International Conference on Computational Linguistics. 2018. p. 1099–109.

[19] Cai C. Automatic essay scoring with recurrent neural network. Proceedings of the 3rd International Conference on High Performance Compilation, Computing and Communications. 2019. p. 1–7.

[20] Nadeem F, Nguyen H, Liu Y, Ostendorf M. Automated essay scoring with discourse-aware neural models. Proceedings of the fourteenth workshop on innovative use of NLP for building educational applications. 2019. p. 484–93.

[21] Zazo R, Lozano-Diez A, Gonzalez-Dominguez J, T. Toledano D, Gonzalez-Rodriguez J. Language identification in short utterances using

long short-term memory (LSTM) recurrent neural networks. PLoS One. 2016;11:e0146917.

[22] Cai W, Cai Z, Zhang X, Wang X, Li M. A novel learnable dictionary encoding layer for end-to-end language identification. 2018 IEEE international conference on acoustics, speech and signal processing (ICASSP). IEEE; 2018. p. 5189–93.

[23] Liang G, On B-W, Jeong D, Kim H-C, Choi GS. Automated essay scoring: A siamese bidirectional LSTM neural network architecture. Symmetry (Basel). 2018;10:682.

[24] Xia L, Guan M, Liu J, Cao X, Luo D. Attention-based bidirectional long short-term memory neural network for short answer scoring. Machine Learning and Intelligent Communications: 5th International Conference,

MLICOM 2020, Shenzhen, China, September 26-27, 2020, Proceedings 5. Springer; 2021. p. 104–12.

[25] Uysal I, DOĞAN N. How Reliable Is It to Automatically Score Open-Ended Items? An Application in the Turkish Language. Journal of Measurement and Evaluation in Education and Psychology. 2021;12:28–53.

[26] Nematzadeh, S. , Kiani, F. , Torkamanian-Afshar, M. , & Aydin, N. . (2022). Tuning hyperparameters of machine learning algorithms and deep neural networks using metaheuristics: a bioinformatics study on biomedical and biological cases. Computational biology and chemistry(97-), 97.

# Application of Image Style Transfer Based on Normalized Residual Network in Art Design

Jing Pu, Yuke Li[*]

School of Arts and Media, Sichuan Agricultural University, Ya'an, 625014, China

*Abstract*—**With the development of computer vision technology, image style transfer technology based on deep learning has achieved vigorous development. It has been widely applied in fields such as art design, painting creation, and film and television effect production. However, existing image style transfer methods still have shortcomings, including low efficiency and weak quality of style transfer, which cannot better meet the actual needs of various art and design activities. Therefore, a residual network structure is introduced to construct an image style transfer model based on the convolutional neural networks. Meanwhile, a normalization layer is added to the residual network results to optimize the image style transfer technology. An image style transfer model based on the normalized residual network is constructed. The experimental results show that the accuracy, recall, and F1 values of the improved image style transfer model proposed in the study are 97.35%, 96.49%, and 97.52%, respectively, which can complete high-quality image style transfer. This indicates that the image style transfer model proposed in the study has good performance, which can effectively improve the efficiency and quality of image style transfer, providing effective support for various art and design activities.**

*Keywords—CNN; residual network; normalization; image segmentation transfer; art and design*

## I. INTRODUCTION

With the development of technology and social progress, various digital media have become an indispensable part of daily life. As a medium for the public to showcase their unique pursuit of individuality, the demand for artistry in images is increasing. Many scholars have begun to explore how to automatically synthesize images with artistic style through computers [1]. Style transfer emerged as the times require. Image style transfer is often regarded as a universal texture generation method for research. Therefore, image style transfer (IST) has become a research highlight. IST technology refers to the process of converting an image into an image that is similar in style or content to the target image through machine learning methods and other techniques [2, 3]. With the progress of deep learning (DL) technology, some scholars build image style migration methods based on the advantages of Convolutional neural network (CNN) feature extraction, while others propose to build image style migration methods using encoder and decoder models [4]. However, existing image style transfer methods have a slower speed during the transfer process. It cannot meet the application requirements in real scenarios. Meanwhile, the comprehensive quality of style images obtained by existing image style transfer methods is not high. In deep learning technology,

convolutional neural networks are feedforward neural networks based on convolutional operations and have deep structures. They are widely used in fields such as image perception, image analysis, image classification, and natural language processing. Therefore, based on the existing CNN structure, an improved image style transfer method is constructed [5]. The structure of CNN is optimized by introducing residual network. At the same time, in the image transfer model, besides adding residual blocks, a normalization layer is added to solve the image quality problems. An image style migration Generative model based on the deep residual network instance normalization (ResNet-IN) is constructed. It is expected to achieve higher quality image style transfer, and improve the speed and efficiency of IST.

The research mainly includes five sections. The Section I is an introduction, briefly introducing the research background. The Section II mainly introduces the research review of residual networks and image generation methods based on deep learning. The Section III constructs an image style transfer method based on a normalized residual network. The Section IV validates the performance of the constructed method. The Section V summarizes the research results and points out the future research direction.

## II. RELATED WORKS

A residual network is composed of multiple residual blocks stacked together, which has the advantages of easy optimization and improved accuracy. The internal residual blocks use jump connection, which relieves the vanishing gradient caused by increasing in depth network. Therefore, it is widely used in various fields. Liu et al. conducted recognition research on Boletus images using residual networks. The Fourier transform near-infrared spectral information of the uneven stipe of Boletus edulis was collected. This information was combined into four data matrices to accurately evaluate and identify different Boletus species. According to the findings, the residual neural network (ResNet) has better performance [6]. Liu et al. proposed a data augmentation method to address the issue of limited and imbalanced sample data for transformer faults. A deep residual network with identified paths was introduced to construct a fault diagnosis model, enabling effective transmission and updating of weight parameters. According to the findings, it can effectively expand the data samples with high similarity to the original data. The ResNet has strong feature extraction ability. It enhances the accuracy of fault diagnosis [7]. The existing automatic sleep staging algorithms have too many parameters and long training time, which leads to poor sleep

staging efficiency. Therefore, Yun L et al. proposed an automatic sleep staging algorithm depending on Transfer learning for random deep residual networks (TL-SDResNet) using single channel EEG signals. Experiments have shown that this model can complete rapid training of data. The overall performance is superior to other classic algorithms, with certain practical value [8]. Yousefzadeh et al. introduced an image retrieval system based on the expanded residual CNN of Triplet loss. This system had fewer parameters and provides acceptable accuracy in top-level retrieval images. Experimental evaluation shows that the model can extract more abundant information by expanding the Receptive field, improving the accuracy of image retrieval without increasing the depth or complexity of the model [9]. Siuly et al. proposed a feature extraction method based on deep ResNet to automatically extract representative features from Electroencephalography signal data of schizophrenic patients to identify schizophrenia. This method includes three stages: average filtering for signal preprocessing, deep ResNet for extracting EEG signals, and softmax layer for schizophrenia classification. The research results indicate that it has the ability to discover important biomarkers for automatic diagnosis of schizophrenia from EEG, which will help experts develop computer-aided diagnostic systems [10].

In recent years, image generation and style transformation based on DL have been widely applied. Many breakthroughs have been made. The process of IST has a common idea, which is to analyze images with a certain style. Then corresponding mathematical or statistical models are established for that style. The image to be transmitted is modified to better fit the established model. Wang J combined k-means and semantic closed natural matting algorithms for image segmentation. Neural networks are used for style and content in images. Then through image reconstruction technology, the obtained images are synthesized to achieve the transfer of Folk costume style. The results show that the average runtime, memory usage, and styles generated by this method are 0.06s, 136.06MB, and 1, respectively, reflecting high efficiency and flexibility [11]. Huang et al. proposed an algorithm involving semantic segmentation and residual networks. VGG16 was used for feature extraction to improve the efficiency and generation speed of local IST. Experiments have shown that it is more useful than other commonly used strategies. It can be applied in many specific fields, such as beauty cameras on smartphones, computer-generated images in advertisements and movies, and computer tomography images [12]. Daneshvar et al. proposed a IST method based on neural networks. By manipulating two given camouflage modes, a mixed camouflage mode is generated. The content and style of a CNN trained on image recognition are represented by the correlation between feature maps. The subjective evaluation results indicate that this method is effective in generating successful camouflage patterns [13]. Tian et al. proposed a new layout analysis and style fusion system structure for image generation and style conversion. The Generative adversarial network and multi style ancient book background model were used to train the model. In the experiment, ancient materials such as Yi characters, ancient Chinese, Jurchen characters and ancient paintings were selected as samples for testing. According to the findings, it

improves the performance of the Generative model [14]. Chen et al. constructed a conversion method consisting of multiple convolutional filter banks to better achieve image style conversion. Each filter bank (FB) clearly represents a style. To convert the image into a specific style, the corresponding FB operates on the intermediate features generated by a single automatic encoder. The style library and automatic encoder are learned in a joint manner. The results indicate that this method can effectively achieve image style conversion [15].

In summary, relatively rich research results have been achieved on residual networks and image style transfer techniques. However, in existing research, various image style transfer techniques proposed are mainly designed for specific images, such as clothing, ancient Chinese characters, etc. The practicality cannot meet the needs of various artistic creation activities. At the same time, existing image style transfer technologies have shortcomings in terms of efficiency and quality, and cannot achieve high-quality style image transfer. Furthermore, with the development of computer vision technology, the application demand for image style transfer in various art designs is becoming increasingly widespread. Therefore, based on existing research results and the advantages of residual network structure in image feature processing, a normalized residual network based image style transfer model is constructed. It is expected to further expand the application scope of image style transfer technology through this method, improve the quality and efficiency of image style transfer, and meet a wider range of artistic design needs.

## III. IST GENERATION NETWORK DESIGN BASED ON NORMALIZED RESIDUAL NETWORK

IST is crucial for in various art and design activities. Therefore, this chapter will design the corresponding IST model based on CNN. Meanwhile, the normalized ResNet is applied to optimize the image style Generative model to better realize the IST.

### A. IST Based on CNN

In the computer vision, IST is a common texture production method, which extracts texture feature information from an image and inputs the extracted texture feature information into the target image to obtain a stylized image. CNN is the most effective machine learning network in image migration processing. CNN is a feedforward neural network based on convolution operation, which is extensively applied in image perception, image analysis, classification and other fields [16]. The CNN is composed of convolution layer, pooling layer and full connection layer. Fig. 1 illustrates the basic structure.
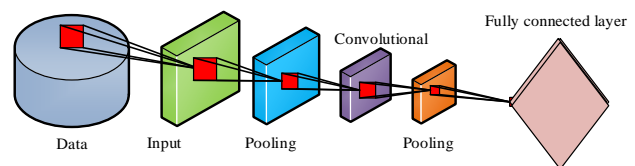


Fig. 1. Structure diagram of CNN.

In the CNN, VGG-Net network structure shows better performance in digital image processing. The research takes VGG-19 as the basic network structure for image style transfer. When the CNN completing the forward propagation task, the convolution core slides in the image matrix. By performing a convolution operation with the pixel values of the convolution kernel coverage position, the corresponding feature map is obtained, as shown in Formula (1).

$$S(i,j) = \sum_m \sum_m I(i+m, j+n)K(m,n) \qquad (1)$$

In Formula (1), $I$ stands for the input image of CNN. $S(i,j)$ stands for the coordinate position of the feature image. $K$ represents a convolutional kernel of size $m \times n$. The convolution operation process of the input image is shown in Fig. 2.
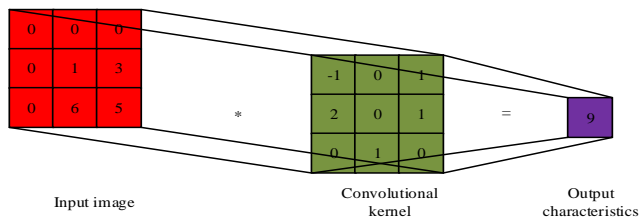


Fig. 2. Schematic diagram of convolution operation.

Firstly, the input image is defined as $x$. The output image is the expected image after transfer, represented as $y$. The convolutional layer used in the style transfer process is $l$. The convolutional features obtained from the input image after calculation in layer $l$ are represented as $M_{ij}^l$. Among them, $i$ stands for the $i$-th channel in the convolutional layer. $j$ stands for the $j$-th position in the convolutional layer. The convolutional features of the image $y$ after style transfer in the $l$-th layer are represented as $F_{ij}^l$. Therefore, the obtained image content Loss function (LF) is shown in Formula (2).

$$Loss(x,y,l) = \frac{1}{2} \sum_{i,j} (F_{ij}^l - M_{ij}^l)^2 \qquad (2)$$

The content Loss function can describe the difference between the style of the input image and the output image. The smaller the value, the smaller the differences between the image before and after the style transfer. Then the style features of the image are defined. The image style is represented by Gram matrix (GM), which is a Symmetric matrix composed of several vector inner products, as shown in Formula (3) [17].

$$G_{ij}^l = \sum_k F_{ik}^l F_{jk}^l \qquad (3)$$

In Formula (3), $G_{ij}^l$ represents the white noise image matrix. $k$ represents the $k$-th position in the convolutional layer. The style error after image transfer is shown in Formula (4).

$$E_l = \frac{1}{4N_l^2 M_l^2} \sum_{i,j} (G_{ij}^l - A_{ij}^l)^2 \qquad (4)$$

In Formula (4), $M_l$ and $N_l$ represent the height and width of the $l$-th layer. $G^l$ represents the $l$-th layer GM of the input image $x$. The GM of the $l$-th layer of the migrated output image $y$ is $A^l$. $E_l$ satnds for the GM of image style. Formula (4) has been simplified as shown in Formula (5).

$$Loss_{style}(x,y) = \sum_l \omega_l Loss_{style}(x,y,l) \qquad (5)$$

In Formula (5), $\omega_l$ satnds for the weight of the $l$-th layer. The content LF and style LF of IST are established through CNN. IST can be seen as the unity of content and style. After copying the target image for style transfer, whether an image is closer in content or more similar in style depends on the proportion of content loss and style loss in the total loss. Thus, the total LF is shown in Formula (6).

$$Loss_{total}(O_{style}, O_{conctent}) =$$
$$\alpha Loss_{style}(O_{style}, R) + \beta O_{conctent}(O_{conctent}, R) \qquad (6)$$

In Formula (6), $O_{conctent}$ stands for the expected content image. $O_{style}$ stands for the expected style image. $R$ stands for the image that needs to be generated. $Loss_{content}(O_{content}, R)$ represents the content LF. $Loss_{style}(O_{style}, R)$ is the style LF. $\alpha$ and $\beta$ are hyperparameters used to measure the proportion of style loss and content loss in total loss. The results of IST based on CNN usually cannot preserve the local texture features of the original image. Therefore, there are issues with the representation of depth features and the accuracy of image transfer models when using this method for image style transfer.

### B. Image Style Transfer Model Construction Based on Improved Normalized Residual Network

The IST network model, as a type of generative network, should have strong feature learning ability and can achieve accurate and reasonable processing of various image features. In response to the shortcomings of the above image style transfer methods, a residual network structure is introduced to construct an improved normalized residual network (ResNet-IN) image style transfer model. The residual module is added to the basic CNN structure. Deep residual neural network is a meaningful branch in the DL. ResNet can effectively solve the defect of gradient disappearance in the training of CNN by introducing residual blocks. It is widely used in fields such as image classification, object detection, and face recognition [18]. The core of ResNet is residual blocks. In the convolution layers with different depths of the CNN, ResNet introduces a special connection layer for information transmission, that is, skip connections, as shown in Fig. 3.
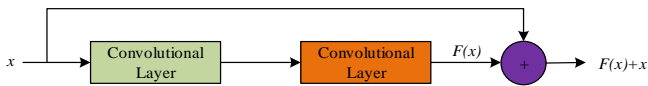
Fig. 3. Schematic diagram of residual block.

Jumping connections can cross a multi-layer network structure to establish a connection between two non-adjacent convolutional layers, thereby achieving information transmission. In Fig. 3, $x$ represents the feature image output from the previous network layer. Then, $x$ is input into the residual block for convolution operation. Finally, the features containing residual information and $F(x)$ are output. The expression of $F(x)$ is shown in Formula (7).

$$F(x) = W_{2\sigma}(W_1 x) \quad (7)$$

In Formula (7), $W_1$ and $W_2$ stands for the weights of the weight layer, respectively. $\sigma$ represents the excitation function. The final output of the residual block is represented as $H(x)$, as illustrated in Formula (8).

$$H(x) = F(x) + x \quad (8)$$

When constructing an image style transfer model, it includes a residual network module and a sampling network module. The image undergoes a two-step convolution operation to achieve down-sampling. Then it is sent to the residual network module for processing. On a convolution with a step size of 1/2, it is sampled and restored to the original size output network. The basic process is shown in Fig. 4.
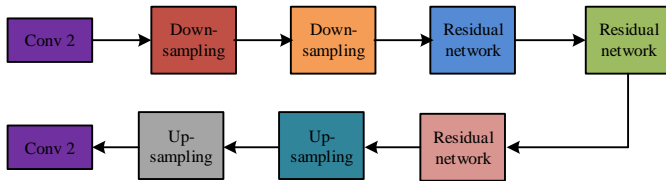


Fig. 4. The basic process of residual block sampling.

In this process, the output part of the network uses the Tanh function to limit the image pixel value between [0, 255]. The image style transfer generation network constructed through research is regarded as the objective function $y = f(x)$. $x$ represents the initial image. $y$ stands for the image after style transfer. $\hat{y}$ stands for the output value. $\phi_z(x)$ refers to the value of the Activation function of layer $z$. In volume $z$, the output value of the Activation function is a feature mapping of $C_z \times H_z \times W_z$. $C_z$ represents the feature maps. $H_z$ and $W_z$ represent the length and width of the convolutional layer. The Euclidean distance between the feature maps of the objective function to be optimized is shown in Formula (9).

$$l_{feature}^{\phi,z} = \frac{1}{C_z H_z W_z} \left\| \phi_z(y) - \phi_z(\hat{y}) \right\|_2^2 \quad (9)$$

Currently, the commonly used residual generation network can achieve rapid transfer of image styles. However, the final image migration effect cannot achieve the expected results. Therefore, the normalization idea is adopted to improve the residual generation network. In the image transfer model, in addition to adding residual blocks, a normalization layer is also added. This structure is to solve the contrast problem that occurs during the implementation of style transfer in the initial image. The contrast of the migrated image generated by the IST generation network is less affected by the contrast of the content image, resulting in a higher quality IST effect. Specifically, the IST network includes basic operations such as convolution, redundation, sampling, and normalization. $x \in R^{B \times C \times W \times H}$ stands for the image. $x_{bcwh}$ stands for the $bcwh$-th element. $b$ represents the image serial number. $c$ represents the RGB channel of the image. $w$ and $h$ stands for spatial dimensions. The normalization result of image contrast is shown in Formula (10).

$$y_{bcwh} = \frac{x_{bcwh}}{\sum_{w=1}^{W} \sum_{h=1}^{H} x_{bcwh}} \quad (10)$$

However, the basic batch normalization layer defines normalization on all images in the dataset. This normalization method is greatly affected by noise and consumes a lot of storage, resulting in low applicability. Therefore, the Instance Normalization (IN) method is introduced to normalize each sample image one by one. The mathematical definition is shown in Formula (11) [19].

$$\begin{cases} IN(x) = \gamma\left(\frac{x - \mu(x)}{\sigma(x)}\right) + \beta \\ \mu_{bc}(x) = \frac{1}{HW} \sum_{h=1}^{H} \sum_{w=1}^{W} x_{bchw} \\ \sigma_{bc}(x) = \sqrt{\frac{1}{HW} \sum_{h=1}^{H} \sum_{w=1}^{W} [(x_{bchw} - \mu_{bc}(x)]^2} \end{cases} \quad (11)$$

The specific process of instance normalization operation is shown in Fig. 5.

Instance normalization is used to replace the task of batch normalization. It can effectively enhance the learning efficiency of the model and avoid various changes in data statistical characteristics. The effect of IST is often evaluated as Mean Intersection over Union (MIoU). The obtained style transfer images are evaluated using the MIOU indicator [20]. MIoU is the standard metric for semantic segmentation, which is typically used to calculate the intersection and union ratio of two sets. In the measurement of IST, two sets are style images and style transfer images, respectively. The calculation method is shown in Formula (12).

$$MIoU = \frac{1}{k+1} \sum_{i=0}^{k} \frac{p_{ii}}{\sum_{j=0}^{k} p_{ij} + \sum_{j=0}^{k} p_{ij} - p_{ii}} \quad (12)$$
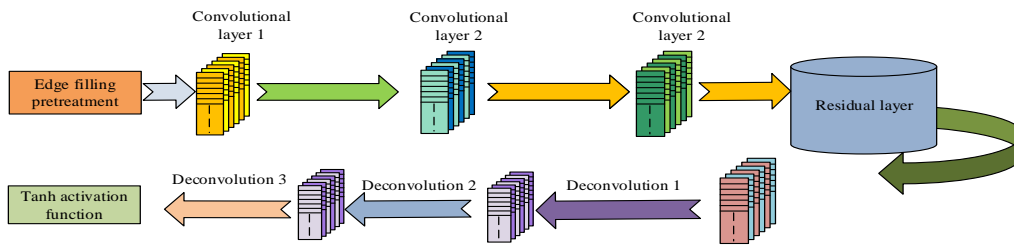
Fig. 5.    Image style transfer process based on instance normalization operation.

In Formula (12), $k$ is pixel quantity. $p_{ij}$ represents the intersection to union ratio of each pixel. $i$ stand for the true value. $j$ stand for the prediction. The larger the MIoU is, the smaller the difference between the predicted and the true value. In IST, the closer the style transfer image is to the initial style image.

## IV. PERFORMANCE ANALYSIS OF IST GENERATION NETWORK BASED ON NORMALIZED RESNET

A Generative model of IST based on normalized residual network is constructed on the basis of CNN. This chapter will test and verify the performance of the image style Generative model. Then the model is applied to actual IST and the transfer effect is analyzed.

### A. Performance Analysis of Improved Normalized Residual Network

To better validate the performance of the image style transfer model based on an improved normalized ResNet, relevant experiments are designed to verify the availability of this method. The environmental design is illustrated in Table I.

TABLE I.        TEST ENVIRONMENT SETTINGS

| CPU Model | Intel@core i7-7700k **CPU@4.2GHz x8** |
|---|---|
| GPU model | GeFore GTX 1080 Ti/PCle/SSE2 |
| Python version | 2.7.13 |
| Tensorflow version | R1.0 |
| CUDA version | 8.0 |
| Bazel version | 0.7.0 |
| Cudnn version | V5.1 |
| Batchsize | 4 |

Firstly, the availability of the IST based on residual network is verified. The dataset used in the model training process is Microsoft COCO, which contains over 80000 images. 5000 images are randomly selected for model training, and an additional 1500 images are selected as the test set. The image feature data is input into the residual CNN for iterative training. The LF is used at the output end of the model to predict the error. The LF and training accuracy of the proposed method under different Learning rate are illustrated in Fig. 6. From Fig. 6, when the Learning rate is 0.0001, the model is prone to over fitting. When the Learning rate is 0.01, the model precision does not get the optimal solution. When the Learning rate is 0.001, the loss value of the model is 0.2. The corresponding accuracy fluctuation under the Learning rate is the smallest and the accuracy is the best. Therefore, 0.001 is taken as the Learning rate of model training.
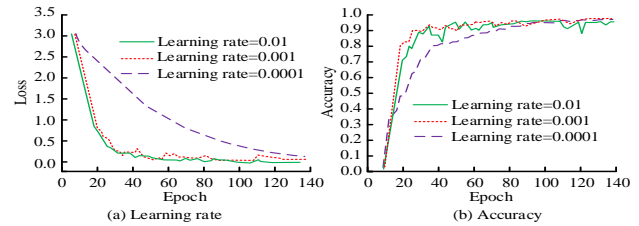


Fig. 6.    Loss value and accuracy rate under different learning rate.

To better compare the performance of different methods, the IST method based on improved normalized residual network proposed in the study is compared with commonly used methods. CNN algorithm, based on batch normalization of image style transfer model (CNN-BN), Fast Neural Style Transfer (FNST), and A Neural Algorithm of Artistic Style (NAAS) algorithms are used for comparison [21]. The AUC values of several models were compared on the training and testing sets, as displayed in Fig. 7. In Fig. 7(a), on the training set, the AUC value of the ResNet-IN model reaches 0.985, which is significantly higher than the other three methods. In Fig. 7(b), on the test set, the AUC value of the ResNet-IN model reaches 0.993, which is also superior to the other three comparison methods in terms of performance. According to the AUC values, the ResNet-IN model constructed in the study has better performance.
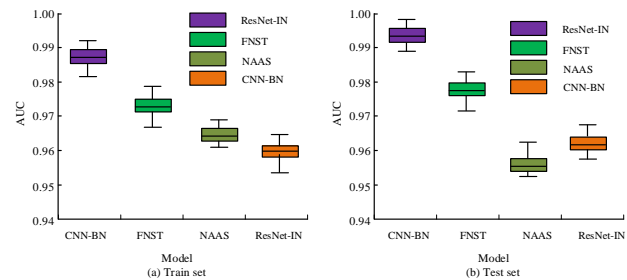


Fig. 7.    AUC value of three models.

The accuracy of several common methods is verified. The changes of Loss function and accuracy of different models are obtained as shown in Fig. 8. In Fig. 8, among the common image style transfer methods, the CNN-BN method has the lowest accuracy, only 82.51%. NAAS has an accuracy of 85.69%. FNST has an accuracy of 91.26%. The ResNet-IN method used in the study has an accuracy of 95.73%. At the same time, considering the loss rates of different methods, the ResNet IN has the best loss value. This indicates that the ResNet-IN image style transfer method has the best performance, which can obtain higher accuracy transfer images.

(a) Accuracy changes of different methods   (b) Loss changes of different methods
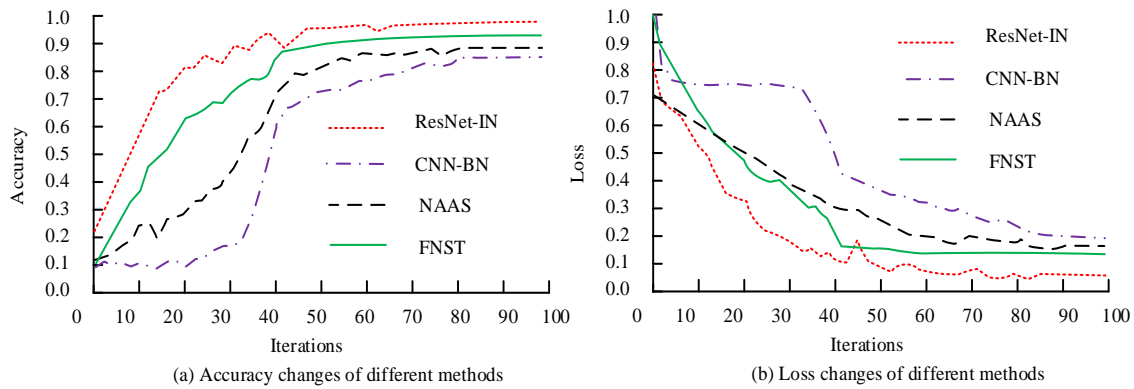
Fig. 8. Changes in accuracy and loss values of different methods.

## B. Application Effect Analysis of IST Generation Network based on Normalized ResNet

To explore the transfer effect of the image style transfer model based on normalized residual network proposed in the study on different style images, eight types of images with different styles are selected for five tests. Table II illustrates the experimental results. From Table II, in this testing platform, there are small differences in the time required for each style transfer test for eight different style images. However, overall, the actual time required for image transfer with different styles is less than 3.5s, indicating a better efficiency in image style transfer.

To test the performance of the image style transfer model constructed in the research, a satisfaction survey is conducted on the transfer effects of eight different styles of images. The comprehensive satisfaction evaluation indicators include completeness, fluency, and coherence. The satisfaction score is 10 points. The comprehensive satisfaction results of the expert's evaluation are shown in Fig. 9. From Fig. 9, taking Style 1, Style 3, and Style 8 as examples, the satisfaction results are as follows. The satisfaction rates for fluency, coherence, and integrity of the transfer map in Style 1 are 7.02, 8.56, and 7.64, respectively. The satisfaction rates for fluency, coherence, and integrity of the transfer map in Style 3 are 7.86, 8.62, and 7.49, respectively. The satisfaction rates for fluency, coherence, and integrity of the transfer map in Style 8 are 7.43, 7.74, and 8.35, respectively. The experimental results show that the overall satisfaction of the image style transfer model is high, demonstrating the excellent applicability of the model.
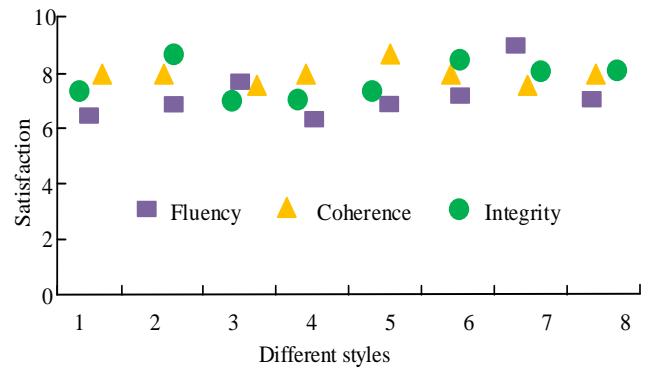


Fig. 9. The satisfaction results of different styles.

Comparing the proposed method with commonly used methods, the MIOU values of the image style transfer method obtained are illustrated in Table III. From Table III, the MIOU value of the CNN based image style transfer method is 0.728, and the image transfer effect of this method is the weakest. The MIOU value of CNN-BN is 0.82, FNST is 0.864, and NAAS is 0.858. The difference between these three methods is relatively small. The MIOU value of the ResNet-IN method is the highest, at 0.9, indicating that the image achieved using this method is closest to the original image, and the difference between the two is the smallest. The image style restoration obtained using this method is the best.

TABLE II. Efficiency Comparison of Different Styles of Images

| Image Style Migration Category | Test Platform | 1 | 2 | 3 | 4 | 5 | Average Time of 5 Tests (S) |
|---|---|---|---|---|---|---|---|
| Style 1 | Android | 2.03 | 2.17 | 2.45 | 1.86 | 1.99 | 2.1 |
| Style 2 | Android | 1.34 | 1.25 | 1.57 | 1.46 | 1.42 | 1.408 |
| Style 3 | Android | 2.34 | 2.16 | 2.75 | 2.09 | 2.45 | 2.358 |
| Style 4 | Android | 2.64 | 3.17 | 2.88 | 3.23 | 3.03 | 2.99 |
| Style 5 | Android | 3.16 | 2.98 | 3.25 | 3.11 | 3.23 | 3.146 |
| Style 6 | Android | 2.94 | 2.56 | 2.73 | 2.46 | 2.38 | 2.614 |
| Style 7 | Android | 2.45 | 2.29 | 2.37 | 2.58 | 2.64 | 2.43 |
| Style 8 | Android | 2.87 | 3.15 | 3.06 | 3.11 | 3.24 | 3.086 |

TABLE III. MIOU COMPARISON OF IMAGES WITH DIFFERENT STYLES

| Model | Number of Tests | | | | | |
|---|---|---|---|---|---|---|
| | *1* | *2* | *3* | *4* | *5* | *Average value* |
| ResNet-IN | 0.85 | 0.89 | 0.94 | 0.87 | 0.95 | 0.90 |
| CNN | 0.64 | 0.69 | 0.67 | 0.85 | 0.79 | 0.728 |
| CNN-BN | 0.78 | 0.84 | 0.85 | 0.81 | 0.82 | 0.82 |
| FNST | 0.87 | 0.86 | 0.80 | 0.91 | 0.88 | 0.864 |
| NAAS | 0.81 | 0.88 | 0.84 | 0.86 | 0.90 | 0.858 |

The performance of several methods in the application process is compared. The results are illustrated in Fig. 10. The accuracy, recall, and F1 values of the ResNet-IN model are 97.35%, 96.49%, and 97.52%, respectively. The three values of NAAS are 95.21%, 94.67%, and 95.23%, respectively. The three values of CNN-BN are 96.38%, 90.77%, and 93.50%, respectively. The three values of FNST are 95.21%, 91.42%, and 93.76%, respectively. The three values of CNN are 90.76%, 91.29%, and 94.08%, respectively. Overall, the ResNet-IN image style transfer method constructed in the study has more advantages in the application process, which can more accurately achieve IST and ensure the quality of style images.
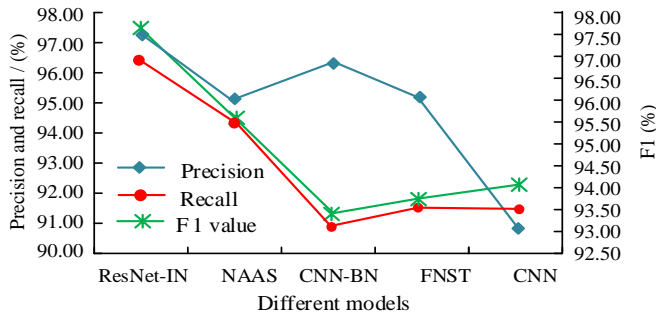


Fig. 10. Accuracy, recall rate and F-measure value of the three models.

V. CONCLUSION

Image style transfer can transfer the style features of one painting to another portrait. With the development of artificial intelligence technology, IST technology based on DL has been widely developed. However, existing image style transfer technologies still have issues of low efficiency and low image quality. Therefore, based on the existing CNN, the ResNet structure is introduced to optimize it. At the same time, the normalization idea is used to improve the contrast problem that occurs during image transfer. The IST network Generative model based on the normalized ResNet is constructed. According to the findings, the AUC values of the ResNet-IN model proposed in the study are 0.985 and 0.993 in the training and testing sets, significantly higher than those of commonly used methods. Among several common image style transfer methods, the CNN-BN method has the lowest accuracy, only 82.51%. The accuracy of NAAS is 85.69%. The accuracy of FNST is 91.26%. The accuracy of the ResNet-IN method used in the study was 95.73%. The ResNet-IN image style transfer method proposed in the study has the best performance and can obtain higher accuracy transfer images. From the perspective of image restoration obtained by different style transfer methods, the proposed image style transfer method has the highest MIoU value of 0.9.

The style transfer image achieved using this method is closest to the original image, with the smallest difference between the two. The image style restoration obtained using this method is the best. Through testing eight different style images, there are small differences in the time required for each style transfer test. Overall, the actual time required for image transfer with different styles is less than 3.5 seconds, indicating a better efficiency in IST. In summary, the IST model proposed in the study can significantly improve the efficiency and quality of image style transfer, provide support for art and design activities represented by painting, and meet the needs of image style transfer in more practical scenarios. However, there are still shortcomings in the research. There are shortcomings in the flexibility of IST. Therefore, in future research, further research is needed on the flexibility of IST. However, there are still shortcomings in the research. The existing image style transfer methods are mainly influenced by factors such as algorithm execution speed, flexibility, and image quality. Although the proposed method has optimized the execution speed and the quality of image extraction, it still has shortcomings in the continuity of image style features. In addition, this model can only complete the transfer of similar image styles after each completion, which has shortcomings in flexibility methods. Therefore, in future research, based on the continuity of image feature extraction and the flexibility of image conversion, the image style transfer ability will be further optimized.

REFERENCES

[1] Vasavi S, Krishna K. Raman S V. Gender prediction using ensemble based wide residual network from surveillance video. Microsystem Technologies, 2022, 29(4): 527-537.

[2] Arthy P S, Kavitha A. Deep Capsule Residual Networks for Better Diagnosis Rate in Medical Noisy Images. Intelligent Automation & Soft Computing, 2022, 36(2): 1381-1393.

[3] Imani M. Spatial and polarimetric information fusion using residual network for polarimetric synthetic aperture radar image classification. IET Radar, Sonar & Navigation, 2022, 16(12): 1963-1976.

[4] Wu Z Q, Xie B. Fine-Grained Pornographic Image Recognition with Multi-Instance Learning. Computer Systems Science and Engineering, 2023, 47(1): 299-316.

[5] Liu D H, Zhao J, Xi A, Wang C, Huang X N, Lai K C, Liu C. Data Augmentation Technology Driven By Image Style Transferin Self-Driving Car Based on End-to-End Learning. Computer Modeling in Engineering & Sciences, 2020, 122(2): 593-617.

[6] Liu H, Liu H G, Li J Q, Wang Y Z. Rapid and Accurate Authentication of Porcini Mushroom Species Using Fourier Transform Near-Infrared Spectra Combined with Machine Learning and Chemometrics. ACS omega, 2023, 8(22): 19663-19673.

[7] Liu X Z, Xie J, Luo Y H, Yang D S. A novel power transformer fault diagnosis method based on data augmentation for KPCA and deep residual network. Energy Reports, 2023, 9(8): 620-627.

[8] Yun L, Zhang X X, Zheng Y C, Wang D H, Hua L Z. Enhance the Accuracy of Landslide Detection in UAV Images Using an Improved Mask R-CNN Model: A Case Study of Sanming, China. Sensors (Basel, Switzerland), 2023, 23(9): 286-294.

[9] Yousefzadeh S, Pourreza H, Mahyar H. A Triplet-loss Dilated Residual Network for High-Resolution Representation Learning in Image Retrieval. Journal of Signal Processing Systems, 2023, 95(4): 529-541.

[10] Siuly S, Guo Y H, Alcin O F, Li Y, Wen P, Wang H. Exploring deep residual network based features for automatic schizophrenia detection from EEG. Physical and engineering sciences in medicine, 2023, 46(2): 561-574.

[11] Wang J. Garment image style transfer based on deep learning. Journal of Intelligent & Fuzzy Systems, 2023, 44(3): 3973-3986.

[12] Huang L, Wang P, Yang C F, Tseng H W. Rapid Local Image Style Transfer Method Based on Residual Convolutional Neural Network.Sensors and materials: An International Journal on Sensor Technology, 2021, 33(4):1343-1352.

[13] Daneshvar E, Tehran M A, Zhang Y J. Hybrid camouflage pattern generation using neural style transfer method. Color Research and Application, 2022, 47(4): 878-891.

[14] Tian Y, Chen S, Zhao F, Lin X, Xiong H. The Layout Analysis of Handwriting Characters and the Fusion of Multi-Style Ancient Books' Background. Journal of Computer-Aided Design & Computer Graphics, 2020, 32(7): 1111-1120.

[15] Chen D, Yuan L, Liao J, Yu N H, Hua G. Explicit Filterbank Learning for Neural Image Style Transfer and Image Processing. IEEE Transactions on Pattern Analysis and Machine Intelligence, 2021, 43(7): 2373-2387.

[16] Hu M, Rutqvist J, Steefel C I. Mesh generation and optimization from digital rock fractures based on neural style transfer. Journal of Rock Mechanics and Geotechnical Engineering, 2021, 13(4):912-919.

[17] Chen H, Han Q, Li Q, Tong X J. Image steganalysis with multi-scale residual network. Multimedia Tools and Applications, 2022, 82(14):22009-22031.

[18] Wang L, Wang L, Chen S. ESA-CycleGAN: Edge feature and self-attention based cycle-consistent generative adversarial network for style transfer. IET Image Processing, 2022, 16(1):176-190.

[19] Wang X, Cheng M, Eaton J, et al. Fake node attacks on graph convolutional networks. Journal of Computational and Cognitive Engineering, 2022, 1(4): 165-173.

[20] Sun Y H, Liu Y. Model-data-driven P-wave impedance inversion using ResNets and the normalized zero-lag cross-correlation objective function. Petroleum Science, 2022, 19(6): 2711-2719.

[21] Iseringhausen J, Weinmann M, Huang W, Hullin M B. Computational Parquetry: Fabricated Style Transfer with Wood Pixels. ACM Transactions on Graphics, 2020, 39(2): 1-14.

# Establishment and Optimization of Video Analysis System in Metaverse Environment

Dandan WANG, Tianci Zhang

School of Digital Media and Art Design
Nanyang Institute of Technology
Nanyang 473000, China

*Abstract*—The current source space communication architecture has not changed. At present, the key technology of so-called metaverse media only applies its elements to existing communication architectures, and more importantly, this type of integration involves individual examples and promotional marketing methods. How to become a new growth point for the deep collaborative development of metaverse media requires strengthened research and exploration. Although AI analysis technology is powerful, its sensitivity, accuracy and adaptability could be more satisfactory due to the complexity of real-world scenarios. Given the shortcomings of existing research, we designed a video analysis system in the metaverse environment, combining virtual reality and artificial intelligence, with video perception, network, and information technology as the medium and big data as the technical support to build a full intelligence Video analysis system. The system is based on the YOLOv3 model, combined with the actual video scene, and analyzes according to the video's human behavior and environmental changes. Experiments show that the system has obvious advantages in the accuracy and recall rate of video analysis and detection, the system detection performance is significantly improved, and the video target analysis and detection of complex scenes are realized.

*Keywords—Artificial intelligence; metaverse; video perception; big data*

## I. INTRODUCTION

In the 1960s, Ivan Sutherland et al. proposed a method to interact in the virtual world and gain experience, which can have a more real human-computer interaction experience [1], [2]. Subsequently, the first virtual reality system was developed. In the 1980s, James David Foley pointed out three elements of virtual reality: interaction, behavior and imaging. He proposed that the next generation of computers will have the complex computing power to realize the communication between users and computers and put forward the concepts of virtual reality, human-computer interaction and so on [3]. Virtual reality technology simulates the human perception function in the simulated computer environment, provides real interactive feedback, and allows people to have an immersive experience. Virtual reality affects the object form in the physical world by its real interactive feeling and good user experience so that users can gain experience in the virtual environment. Virtual reality technology can simulate the real video scene and detect the target of the real-time monitoring video, which can be adapted to the target detection task under various bad weather and low light conditions. The real-time

video data can be transmitted to the virtual platform to view real-time monitoring in the virtual scene. In 2016, the virtual reality technology innovation and industrial development conference was held so that virtual reality technology has a wider range of applications in 3D printing [4], remote sensing mapping, smart cities, digital museums, teaching and training, game animation, aerospace and other fields.

In 2021, based on virtual reality technology, the concept of "metaverse" was mentioned again. Metaverse integrates virtual reality technology, creates a virtual digital world parallel to the real world through exclusive equipment, and creates a social platform with a strong sense of immersion. Users can produce and live in a virtual environment different from the real world and interact in an immersive metaverse environment. Metaverse includes the following features: user participation in creation, providing exploration space, a fusion of the virtual world and the real world, a fusion of time and space, a fusion of three-dimensional technology and intelligent technology, etc. The primary implementation method of metauniverse is virtual reality technology. VR has the advantages of creating realistic scenes, visualizing abstract content, and creating immersive experiences. Artificial intelligence (AI) technology includes deep learning, natural language processing, etc. [5]. Through the use of AI technology, we can increase the depth of research and improve the accuracy and accuracy of video analysis.

The current application scenarios that can only be monitored are becoming increasingly complex, and its classic abnormal behavior analysis rules can only be applied to some industries in China. The current algorithm rules are difficult to meet in all behavior analysis scenarios. Therefore, many applications are in their early stages and need improvement. The main factors hindering the development of intelligent video surveillance and detection systems are:

*1) Environmental* factors have a significant impact on intelligent video surveillance and detection systems. At present, most video analysis systems are developed based on traditional computer vision technology and do not provide image enhancement functions such as improving video image quality and clarity.

*2) Many* video object analysis lacks objective experimental support. Excessive reliance on reasoning leads to subjective assumptions in the interpretation of unconscious psychological phenomena.

*3)* *There* is a problem of insufficient monitoring accuracy in the experiment. The accuracy of integrated virtual reality technology in video surveillance is not satisfactory.

In the current metaverse environment, the deployment of video monitoring systems plays an important role in preventing and stopping crime, maintaining social and economic stability, and protecting the safety of the life and property of the country and people. For example, video analysis is used in 1300 channels of the Qinghai Tibet railway to comprehensively and effectively protect the safety of the whole railway. The main trend of future development of video analysis is to use deep learning technology to improve detection efficiency and realize real-time and pre-intelligent analysis. Therefore, intelligent video surveillance has become one of the most cutting-edge development fields. High definition, networking and intellectualization are the main development trends of video monitoring technology. Intellectualization refers to using intelligent analysis algorithms to process video data, extract valuable information, and prompt users with key information in the form of alarm, to improve the intellectualization and actual use value of video monitoring systems [6]. Intelligent video analysis technology can transform video monitoring from traditional "passive monitoring" to intelligent "active monitoring" and can free users from monotonous and boring monitoring work, avoid the problem of attention loss caused by long monitoring time, and realize 24-hour monitoring, so it has attracted more and more users' attention.

The research and innovation contributions are as follows:

*1)* *The* metaverse can integrate virtual reality technology and coexist. This means that the research and development of metaverse media is not only reflected in game types, but mainly in social media full scene CNC.

*2)* *This* article constructs a fully intelligent video analysis system. The system is based on the YOLOv3 model, combined with actual video scenes, and analyzed based on human behavior and environmental changes in the video.

*3)* *YOLO3* draws on the residual network structure to form deeper network layers and multi-scale detection, improving the performance of mAP and small object detection.

*4)* *The* system has improved prediction accuracy while maintaining its speed advantage, especially enhancing its ability to recognize small objects.

This article analyzes video analysis and monitoring issues in the metaverse environment. The video analysis system in the metaverse environment has the advantages of high real-time accuracy and strong robustness, fully meeting production needs. The first part introduces the current status of the metaverse environment and video analysis technology. Section II analyzes the problems and development prospects of existing video analysis and detection methods. Section III mainly introduces the requirement analysis, design, and implementation of an intelligent video analysis system based on the metaverse environment. Section IV provides a detailed introduction to the development and testing of the system. Section V provides a summary of the entire text. The experiment shows that the system has significant advantages in terms of accuracy and recall in video analysis and detection,

and the detection performance of the system is significantly improved, achieving video object analysis and detection in complex scenes.

## II. RELATED WORK

Intelligent video analysis technology is gradually applied in digital video surveillance and has been developed for over 10 years. However, regarding the current development level and actual use of intelligent video analysis technology, smart video analysis technology has only made small-scale applications in some industries, such as banking, transportation, and justice, and more often, it is only used as a highlight demonstration of the project. The market for intelligent video analysis technology has remained the same. The main reason is a large deviation between the user's cognition and demand for smart products and the degree of intelligence that intelligent products can achieve. This problem is more prominent because some manufacturers adopt the propaganda method of exaggerating performance to occupy the market. From the perspective of the long-term development of intelligent video analysis technology, it should be based on the current technical level, improve adaptability and robustness to different scenarios, simplify product settings, improve ease of use, bring real value to customers, and truly make intelligent video Analytical techniques are widely used. For example, the original monitoring images collected at the front end are structurally analyzed through intelligent video analysis technology. The original video image data are automatically transformed into quasi-structured and structured data to form the corresponding subject database. The data are submitted to the big data platform for relevant data models, technical methods and other uses, developing rich practical applications, such as human and vehicle trajectory characterization, foothold analysis, prediction and early warning and other services, giving full play to the reasonable value of monitoring images.

The rise of artificial intelligence technology and the development of network technology have pointed out new research directions for video analysis technology. Connect the hardware device to an IP network, and the webcam can be read by any device on the network via IP access. At the same time, the connection between various devices in the network relies on the standardized TCP/IP protocol. As long as the machines that meet the requirements of the protocol can access the network, the system's scalability has been greatly enhanced. In terms of algorithm, combined with the current deep learning algorithm, a role in a neural network is constructed to analyze and recognize video targets, which greatly improves the accuracy of analysis and detection. Combined with various embedded devices, controllable management is realized through the Internet/WiFi/LAN. It is highly integrated with access control, voice system, alarm devices, etc., combined with artificial intelligence algorithms to realize automatic detection, personnel identification, identity control and other functions between various machines [7].

Abnormal behavior detection of moving targets is one of the main functions of an intelligent video analysis system. Its primary task is to determine the moving targets then realize the tracking of moving targets in video and abnormal behavior analysis [8]. The traditional method to determine the moving

target is mainly realized by motion detection methods, including (1) the inter-frame difference method, which expands each frame taken by the camera according to the time sequence. Then it makes a difference between the images of the previous and subsequent frames and then regards different places in the video frame as moving targets. The biggest advantage of the inter-frame difference method is that it is simple and fast, while the biggest disadvantage is that it is difficult to separate the complete moving target. (2) Background difference method, first establish the background model of the video, then make a difference between the video frame of the monitoring system and the background model, and then locate the moving target in the video [9]. The biggest advantage of the background difference method is that it can adapt to the complex and changeable surrounding environment, and the biggest disadvantage is that it is easily affected by light. In order to make the background difference method have a good effect, it is necessary to update the background model in time. (3) The optical flow method infers the moving direction and speed of the object according to the change law of the recognized image pixel value with time. Its disadvantage is that it requires a large amount of calculation and a high computer processing capacity.

With the in-depth study of deep learning, target detection based on neural networks has higher accuracy and better stability than traditional target detection methods. It can meet the real-time requirements of video analysis. At present, deep learning algorithms for target detection are mainly divided into two categories: the two-stage method, whose principle is to divide the whole detection process into two parts to generate candidate frames and to identify objects in structures. It mainly includes: (1) region-based convolutional neural networks (R-CNN) target detection method, which greatly improves the accuracy of target detection [10]. The principle is to obtain candidate regions through selective search, then extract the features of each candidate region using a deep convolution network and carry out support vector machines (SVM) classification, and then obtain preliminary detection results. Finally, to get a more accurate boundary box, we use the deep convolution network feature combined with the SVM regression model again. (2) Fast R-CNN, this method no longer convolutes the candidate regions but convolutes the whole image and completes the fitting of the bounding box and the classification of candidate regions through the structure of the dual task network. Compared with R-CNN, Fast R-CNN shortens the training and testing time by nearly nine times [11]. (3) Faster R-CNN, this method directly generates candidate regions through the convolutional neural network, composed of regional candidate generation network and Faster R-CNN, which realizes candidate region classification and border

regression. This method's training and testing time is 1/10 of that of Faster R-CNN [12]. However, the target detection method based on a convolutional neural network needs to input a fixed-size image, and the normalized production organism is truncated or stretched, which will lead to the loss of some information in the input image. The other is one stage method, whose principle is to unify the whole process and get the detection results directly, which makes the target detection process simple and efficient. It mainly includes (1) YOLO (you only look once), which directly obtains the category and location information of the target through a neural network convolution operation and realizes the real recognition and judgment in one step [13]. YOLO target detection process is very simple, and compared with the above detection algorithm, its efficiency is very high, and the processed image can reach 45 frames per second. (2) Single shot multi-box detector (SSD) [14], this method carries out detection and classification together and filters out some detected results with unclear classification and low scores. It is a detector based on a full convolution network, which can detect objects of different sizes with different layers. However, the target detection model trained by this algorithm will have the problem of positioning errors when identifying targets.

In summary, the nonlinear transformation ability of neural networks is also stronger. In target detection tasks, we need to map the input low dimensional features to a high-dimensional space in order to better represent and distinguish different targets. Traditional methods often require the design of complex mapping functions, and neural networks can learn this mapping relationship from data through automatic learning, avoiding complex design processes. Finally, the training process of neural networks can be automated and parallelized, which greatly shortens training time and improves efficiency. Of course, there are also some challenges and limitations in the target detection methods of neural networks. For example, they require a large amount of data for training and require high-performance hardware and software to run. In addition, the design and training of neural networks also require certain experience and skills, such as selecting appropriate network structures, optimizing algorithms, loss functions, etc.

## III. Establishment and Optimization of Video Analysis System in Metaverse Environment

### A. Traditional Video Detection and Analysis Theory

The traditional target detection system generally comprises three modules, including a region selection module, feature extraction module and classifier classification module, as shown in Fig. 1.



Fig. 1. Traditional food detection and analysis steps.

*1) Region selection:* The main function of the area selection module is to locate the target's location. Because the

mark may appear anywhere in the image, and the target's size and length-width ratio is uncertain, the sliding window

strategy is initially used to traverse the whole picture, and different scales and length-width ratios need to be set. Because the appearance of the target is random, in the selection of the area where the target is located, the target can only be found by traversing and selecting by sliding on the original map, which leads to more redundant target boxes, which not only affects the speed, but also consumes many computing resources, and the detection results are also unsatisfactory. The higher the structure levels, the worse the system's accuracy.

*2) Feature extraction:* The main function of the feature extraction module is to calculate and count the image's local or global feature descriptors to get a feature map with richer semantic meaning. Affected by complex environments and scenes, in the face of diverse scene changes, traditional feature extraction methods are difficult to meet high accuracy requirements, so they can not be adapted to application scenarios. The previous feature extraction is all manually designed features, such as Haar features, hog features, etc. Still, due to the ever-changing world and limited cognitive ability, the artificially created features have various problems, such as poor robustness and unreliability, which makes it difficult to improve the efficiency of traditional target detection.

*3) Classifier classification:* The function of the classifier is to judge the category of a new observation sample based on the training data of the marked category. Traditional classification is mainly realized by AdaBoost and SVM [15]. Two main reasons affect classification: the structure of the classifier itself and the feature parameters extracted through the previous layer.

*B. Overall Function Design of Video Analysis System in Metaverse Environment*

According to the requirements of the system, five functions are realized, including the function of visual interface, the process of controlling the ball machine to track the moving target in real-time, the function of detecting the abnormal behavior of the target, the function of image enhancement and the process of panoramic stitching. The functional structure of the system is shown in Fig. 2.
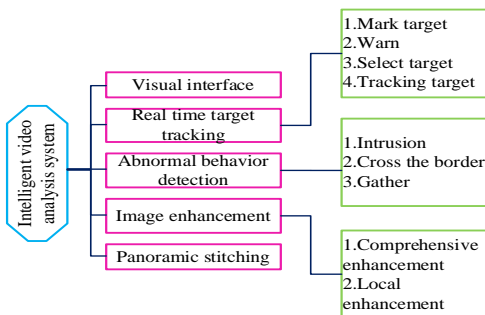


Fig. 2. System function structure diagram.

*C. System Hardware Design*

The main functions of the hardware system in the overall system architecture include data acquisition, video recording,

result display and other parts. The data collected by different hardware is transmitted and summarized into the system software through network communication, and then the collected information is analyzed and processed through the system software. Finally, the results are stored and displayed. For the whole system, the hardware system is the premise to ensure the stability of information collection and the comprehensiveness of information collection. A reasonable hardware system architecture can ensure the stability of information collection. The correct hardware installation method and the appropriate hardware layout position are the prerequisites for comprehensive information collection. The hardware system structure is shown in Fig. 3. In this study, the hardware architecture is constructed using a network camera, network HD hard disk video recorder, monitoring hard disk, display, computer, switch and other hardware.
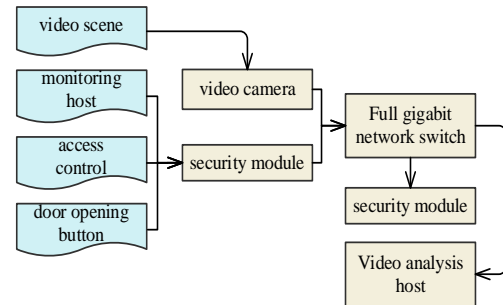


Fig. 3. Hardware system structure diagram.

*D. System Software Design*

The software of the intelligent video analysis system for regional control is mainly composed of four parts: data acquisition module, image processing module, database storage and processing module and result display module. First, the system obtains real-time video information and access control information through the data acquisition module, and then the image processing module performs real-time detection and processing for the monitoring area. The database storage and processing module stores and processes the results of the image processing module and the entry and exit records of the access control all-in-one machine. The result display module displays the real-time processing results of the image processing module, and the database on the interface queries the results or exports them as CSV files. The software flow chart of the intelligent video analysis system is shown in Fig. 4.
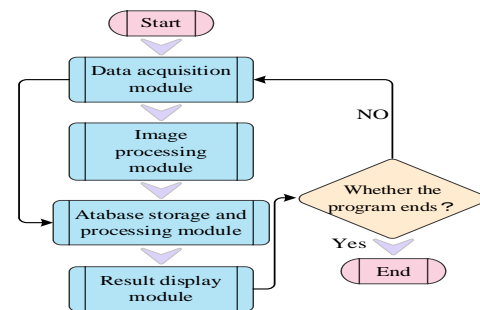


Fig. 4. Flow chart of the video analysis system.

*1) Data acquisition module:* There are two kinds of hardware devices used in the data acquisition module, one is

the surveillance camera, and the other is the integrated access control machine. Among them, the data acquisition of the access control all-in-one machine uses the alarm callback function in its SDK. When someone opens the door through the access control, the alarm callback function is triggered to obtain the personnel job number, access control machine IP, travel time and other related information. The information acquisition of the surveillance camera needs to cooperate with the image processing module. The data acquisition completes the equipment login, decoding, format conversion and other operations in the main thread, and the image processing module processes the converted image in the sub-thread. The multithreading processing method used in this system can not only strengthen the robustness of the system operation but also speed up the system processing speed.

First, the system needs to initialize the device SDK to prepare for the subsequent program operation. Then, the system reads the login device information. Due to different devices, the login and following processing processes are separate. The access control all-in-one machine does not need to maintain a link with the system for data transmission at all times after successful login. Only when someone triggers the alarm callback function when passing through the access control will it return a message containing the device IP to the system? It occupies relatively few computing and memory resources through the personnel job number and passing time, so its data acquisition process is in the same thread. However, the surveillance camera's image information needs to carry out real-time data transmission with the system, so it is necessary to set the disconnection reconnection time and an abnormal callback function to ensure the system's stable operation. After the surveillance camera logs in, each camera will return a device ID number, which will be used to identify subsequent code stream data differentiation of different cameras. After the camera logs in, you need to open the playback library and call the real-time stream callback to set the parameters of the video stream. Then, start the decoding callback to decode the video stream into UV12 format and convert UV12 format into RGB format for subsequent image processing.

Opening up threads and caches for each camera can first make the system process the images of each camera without interference, improve the system's stability, improve the system's computing efficiency, and enhance the real-time performance of the system. Collect image information for each camera's image cache in the system's main processing thread, process the image data in the corresponding sub-processing thread, and empty the processed image cache to keep the video frame cache updated in real-time.

*2) Image processing module:* The image processing module of this system is mainly used in the sub-thread of each camera of the system. The image processing module is the core of this system, which needs to combine the detection algorithm based on a convolutional neural network with the database to complete the work. Among them, the detection algorithm based on a convolutional neural network is used to detect intruders in the set deployment scenario. The database

part is responsible for analyzing the time when the intruders are detected and recording the start time and end time of each intrusion. After obtaining the current frame from the video frame buffer, the image processing module uses the YOLOv3 detection algorithm after fine-tuning the scene to detect the staff. When personnel are detected, the current detection time is determined. If the current detection time is within the preset deployment time, the current detection time is compared with the intrusion time in the database. The design idea of this module is that if there is a repeated intrusion within three seconds, it will be regarded as the same intrusion event. If the interval between the latest and last detected intrusion is greater than three seconds, it will be considered a new intrusion. Therefore, the current detection time is first compared with the latest intrusion end time. If the time difference is less than three seconds, the newest intrusion end time is updated to the current detection time. If the time difference exceeds three seconds, it must be compared with the latest intrusion start time. If the time difference exceeds three seconds, the current time is recorded as the new intrusion start time. Otherwise, it is recorded as the new intrusion end time. After completing the above operations, clear the current frame data, obtain and process the next frame.

*3) Database storage and processing module:* This system's database storage and processing module is mainly used to process the access information returned by the access control machine. Through access control information and face comparison based on video frame images, the system can realize several functions, such as attendance management, overtime detection of non-secret related personnel in hidden related areas, detection of non-secret related personnel entering illegally, and reminder of VIP visits. The four functions of this module are realized by hardware information triggering the query and processing of the database.

*a) Attendance management*: First, the real-time access information returned by the access control is written into the database, and the database information of the previous day is processed at 0:00 every day. Each person's first access is recorded as the time of work, and the time of the last entry is recorded as the time of departure. Then, they are compared with the preset on-off time, the day of the week and other information to obtain whether there are late, early leave, absenteeism or overtime on that day, and store the analysis results.

*b) Overtime* detection of non-secret related personnel in hidden related areas. The deployment site of this system requires that when non-secret-related personnel enter the secret-related room, whether the door is locked or not, they must pass the access control and stays for no longer than the specified time. Therefore, when the system detects that non-classified personnel enter the classified area after a specified time of waiting, it will query the access information of the classified site during the waiting period. If the non-classified person has no record of entering and leaving the classified site within this period, the non-classified person will be recorded as an overtime stay.

*c) Detection of illegal entry of non-secret related personnel*: When the camera at the entrance of the classified area detects that a non-classified person has entered the classified area through face comparison, it determines whether the non-classified person has passed the access control when entering the classified area by querying and analyzing the database. If the result is that he has yet to enter the classified area through access control, record the illegal entry behavior.

*d) Important guest visit reminder*: When the camera outside the main door detects the person through face comparison, it determines whether the visitor is a VIP by querying the VIP information in the database. If it is a VIP, it will send a reminder message.

*e) Result display module*: The results show that the module's structure is relatively simple and consists of two parts. One part displays the real-time detection effect of the image processing module on the software interface, and the other part displays the data queried from the database on the interface in the form of a list and exports it to a CSV format file. This module only displays image data and database data without processing.

### E. Key Technologies of the Video Analysis System

*1) Back propagation algorithm:* The backpropagation algorithm is important for convolutional neural networks to calculate gradients. Dr Paul proposed the backpropagation algorithm werbos in his doctoral thesis in 1974, but it was only widely recognized once David proposed it again in 1986. At present, this is one of the most commonly used algorithms for training neural networks. The input of the neural network structure is a two-dimensional vector $(x_1, x_2)$, and the corresponding parameters to be optimized are $w_1$, $w_2$ and b. The last step of the nonlinear transformation operation is completed by a ReLu [16]. The calculation is divided into the most basic multiplication and addition operations. When backpropagation is required, multiply all the gradients on the dotted line from y to the leaf node.

At present, the most widely used function is the ReLu function. Its linear and unsaturated characteristics give it strong convergence ability in model training.

$$y = \begin{cases} 0 & (x \leq 0) \\ x & (x > 0) \end{cases} \tag{1}$$

In the ordinary ReLu function, for the input less than 0, the derivative is constant to 0, which may cause too many silent neurons. Leaky ReLu [17], as an improved version of the ordinary ReLu, avoids this problem by introducing a normal number $\lambda$ predefined to be close to 0.

$$y = \begin{cases} x & (x > 0) \\ \lambda x & (x \leq 0) \end{cases} \tag{2}$$

Compared with the ReLu function, the PReLu function introduces value α, which is obtained by adaptive learning based on data. The introduction of a can prevent the gradient from disappearing, accelerate the convergence speed and reduce the error rate.

$$y = \begin{cases} x & (x > 0) \\ \alpha x & (x \leq 0) \end{cases} \tag{3}$$

Leaky ReLu and PReLu have the best relative performance based on the above common activation functions. Their linear and unsaturated characteristics can help the model converge quickly. At the same time, they both solve the problem of training termination caused by silent neurons caused by gradient disappearance. However, parameter a in PReLu needs adaptive learning, and the YOLOv3 algorithm is relatively sensitive to speed, so it is necessary to reduce the number of learning parameters so the activation function selected in YOLOv3 is Leaky ReLu.

*2) Gradient descent algorithm:* When YOLOv3 uses the back-propagation algorithm to calculate the gradient, it also uses the gradient descent algorithm [18]. Generally, there are three kinds of gradient descent algorithms: full batch gradient descent, random gradient descent (SGD) and small batch data gradient descent. The full data gradient descent algorithm is to calculate all the training sample data every time the gradient is calculated. If the total number of samples in the training set is N, calculate the entire loss function by calculating the loss function for all N sample data and then calculate the mathematical expectation. The calculation formula is shown in Eq. (4).

$$l(\theta) = \frac{1}{N} \sum_{i=1}^{N} L(\theta; xi, yi) \tag{4}$$

In Eq. (4), *N* is the total amount of training sample set, $(x_i, y_i)$ represents a set of random components, and θ is the parameter to adjust the component weight.

The distance measurement formula used in K-means clustering is shown in Eq. (5).

$$d(box, centroid) = -IOU(box, centroid) \tag{5}$$

In Eq. (5), *d* represents the distance from the centroid to the bounding box, (*box, centroid*) is the geodesic distance from the centroid to the bounding box. IOU (Intersection over Union) is a measure of the accuracy of detecting corresponding objects in a specific dataset.

The second is to improve the problem of unstable model fitting in the traditional anchor algorithm. The instability in the conventional anchor algorithm is mainly caused by predicting the coordinates (*x, y*) of the bounding boxes. The calculation formula is shown in Eq. (6).

$$x = (tx * wa) - xa$$
$$y = (ty * ha) - ya \tag{6}$$

In Eq. (6), $(x_a, y_a)$ represent the coordinates of the center of the bounding box, $t_x$ is the *x* coordinate movement step size, $t_y$ is the *y* coordinate movement step size, $w_a$ is the direction parameter of the *x* coordinate, $h_a$ is the direction parameter of the *y* coordinate. In Eq. (6), no constraints are imposed on the bounding boxes, and any bounding box can fall on any area of the image, which is relatively difficult to stabilize. In YOLOv3, the improved anchor algorithm directly predicts the relative

position of the bounding box relative to the grid unit, and the calculation formula is shown in Eq. (7).

$$bx = \sigma(tx) + cx$$
$$by = \sigma(ty) + cy$$
$$bw = pw\,e^{tw}$$
$$bh = ph\,e^{th} \qquad (7)$$

In Eq. (7), $(c_x, c_y)$ is the coordinate of the upper left corner of the grid, $p_w$ and $p_h$ are the width and height of the anchor box, respectively, and $(b_x, b)$ is the central coordinate of the bounding box, and $b_w$ and $b_h$ are the width and height of the bounding box. After the above constraints, the network becomes more stable.

Compared with the YOLO algorithm that does not use the anchor idea, the map has a slight decrease, but the recall rate has a significant increase, as shown in Table I. Where AP represents the average accuracy of target detection, the map represents the average AP value, and recall represents the ratio of correctly identified targets to the number of all flying targets in the test set. This is because each graph can only give dozens of prediction boxes before using the anchor idea. After using the anchor idea, the model can have more than 1000 prediction boxes, giving the algorithm more room for improvement.

TABLE I.        COMPARISON OF RESULTS WITH AND WITHOUT ANCHOR

|  | **Map** | **recall** |
|---|---|---|
| Without anchor | 69.5 | 81% |
| With anchor | 69.2 | 88% |

*3) Loss function:* In YOLOv3, the key prediction information in the final result mainly includes four categories: prediction frame length and width (w, h), coordinates (x, y), category class and confidence. According to these four information characteristics, the appropriate loss function is selected, and then the weighted average is obtained to obtain the final loss function. Among them, the loss function used in the prediction frame length and width (w, h) is the sum of squares of the errors of the corresponding points of the original data and the fitting data, and its calculation formula is shown in Eq. (8). The closer the SSE result is to 0, that is, $y_i = \hat{y}_i$, it means that the predicted parameters are equal to the real value, the network reaches the convergence state, and the higher the target detection rate, the stronger the fitting ability of the final model.

$$SSE = \sum_{i=1}^{n} wi(yi - \hat{y}i)^2 \qquad (8)$$

The loss function used for the remaining three types of information is the cross entropy loss function binary_crossentropy; the calculation Formula is shown in Eq. (9) and Eq. (10).

$$loss = \sum_{i=1}^{n} \hat{y}i \, log\, y\,i + (1 - \hat{y}i)\, log(\, - \hat{y}i) \qquad (9)$$

$$\frac{\partial loss}{\partial y} = -\sum_{i=1}^{n} \frac{\hat{y}i}{yi} - \frac{\hat{y}i}{yi} \qquad (10)$$

Eq. (10) shows that only when $y_i = \hat{y}_i$, the loss value is 0, and in other cases, the loss is constant as a positive number and the greater the difference between *you* and the greater the loss value.

## IV.  RESULT AND ANALYSIS

According to the video scene's personnel management and control requirements, a detection and analysis scheme suitable for this scene is designed. YOLOv3 is fine-tuned on the video scene data set, and the accuracy of the fine-tuned algorithm is verified through experiments. Finally, the stability of the system is verified.

The CPU of the hardware platform used in this study is i5 4590, and the main frequency is 3.3GH; The GPU is NVIDIA's Teska K40, and the video memory is 12GB; Memory is 16GB; The system is a 64-bit ubuntu16.04 high-performance host. It needs to be done on Darknet. Before installing Darknet, you must first configure CUDA and OpenCV, recompile Darknet on the configured host, and finally get the Darknet framework loaded with CUDA and OpenCV.

After completing the above preparations, set the response path in the program and start the training. After training, a fine-tuned YOLOv3 model with a size of 246.3mb is obtained. The loss image obtained from training is shown in Fig. 5. The loss function is a function to measure the detection performance of the algorithm. In Fig. 5, at the beginning of training, the loss value decreased rapidly, indicating that the fitting speed of the model quickly increased. With the progress of the training process, the decline speed of loss value gradually slows down, indicating that the model fitting is slowly completed. When the training times reach 40000, the loss value is the minimum. In the 40000 and 45000 training, the learning rate is adjusted to the current 1/10, and the loss value tends to be stable and minimum. At this time, the training is completed, and the model reaches the optimal state.
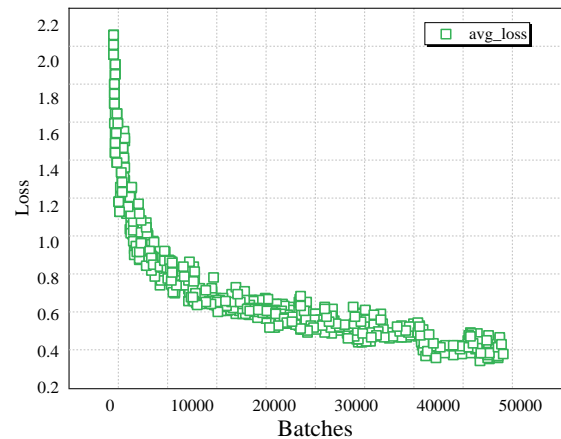


Fig. 5.   Loss function training curve.

Five hundred pictures are cut from the live video images of the sample set as the test sample set. The selected pictures cover as many scenes as possible, and the proportion conforms to the actual application scene. The final test sample focuses on 300 pictures of outdoor areas under natural light during the day, with a total of 1924 personnel targets; 100 pictures of

indoor areas under natural light during the day, with a total of 563 personnel targets. There are 100 pictures in the street backlight scene, with a total of 125 personnel targets. Fig. 6 shows a group of image comparisons under the same angle, natural light in the day and light at night. The performance of system target detection under different light can be studied through the comparison test.



Fig. 6. Training set samples.

There are 2612 personnel targets in the test data, of which 2518 targets were correctly detected, 94 targets were missed, and the background was detected as personnel targets eight times, with accuracy P=0.997, recall rate R=0.964, false alarm rate FA=0.003, and missing alarm rate FNR=0.036. Under the condition of natural light in the daytime, the accuracy P=0.997, the recall rate R=0.960, the false alarm rate FA=0.003, and the missed alarm rate FNR=0.040; Under the condition of night light, the accuracy P=0.996, recall rate R=0.973, false alarm rate FA=0.004, missing alarm rate FNR=0.027; Under the state of the strong backlight at the sightseeing elevator entrance, the accuracy P=1, the recall rate R=0.984, the false alarm rate FA=0, and the missing alarm rate FNR=0.016. The specific test results are shown in Table II.

TABLE II. STATISTICAL TABLE OF OBJECT DETECTION RESULTS OF YOLOv3 MODEL PERSONNEL

|  | TP | FN | FP | R | P | FNR | FA |
|---|---|---|---|---|---|---|---|
| **Daytime indoor conditions** | 1847 | 77 | 6 | 0.960 | 0.997 | 0.040 | 0.003 |
| **Daytime outdoor conditions** | 548 | 15 | 2 | 0.973 | 0.996 | 0.027 | 0.004 |
| **Backlight condition** | 123 | 2 | 0 | 0.984 | 1 | 0.016 | 0 |
| **total** | 2518 | 94 | 8 | 0.964 | 0.997 | 0.036 | 0.003 |
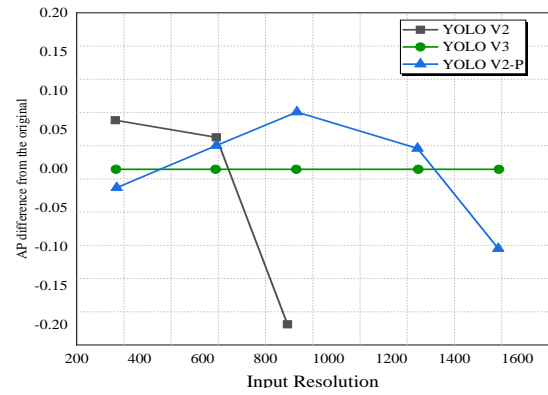


Fig. 7. AP comparison of networks under different resolutions.

As shown in Fig. 7, in the experiment, images of different resolutions are selected to input the network, and the AP of the network is tested. We can find that YOLOv3 has the best AP at high resolution, while YOLOv2 and YOLOv2-p have the best AP at middle and low key, respectively. This means that we can use sub-nets of YOLOv3 models to execute the object detection task well. Moreover, we can perform a compound scale-down of the model architectures and input size of an object detector to get the best performance.
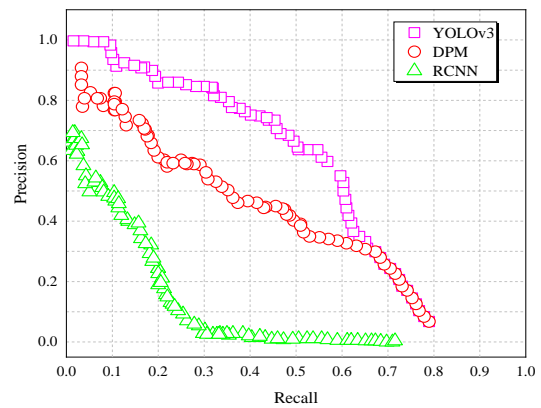


Fig. 8. Dataset precision-recall curves.

The experiment compares the traditional deformable parts model (DPM) target detection algorithm and the target detection algorithm based on RCNN with this method for human detection in the data set. As shown in Fig. 8, it can be seen that the YOLOv3 model still has a high correct detection rate when the recall rate reaches 60%, but the detection rate of the DPM algorithm and the RCNN method decreases significantly. Because the DPM target detection method is characterized by manual marking, it has certain limitations, which leads to performance degradation. After transforming the detection problem into the classification problem of the local area of the picture, the RCNN method cannot fully use the context information of the local features of the image in the whole picture and loses the global attributes, resulting in performance degradation.
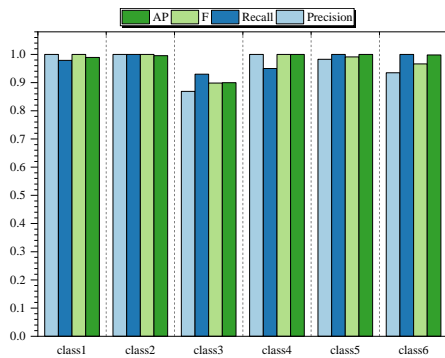
Fig. 9.   Object classification detection accuracy comparison.

As shown in Fig. 9, the experiment selects six types of detection targets in the data set for classification and detection and compares the detection accuracy. It can be seen that the YOLOv3 network model maintains high detection accuracy for six categories of targets. Category three is a selected low-resolution group, contrasting categories with light interference, and the detection accuracy is slightly reduced. Fig. 10 is a simulation of the classification and prediction results of the detection targets by the network; the target classification method is based on the target detection technology to locate the targets in the image, analyze the characteristics, and cluster the targets with the same features to form a certain category. It can be seen from the figure that the network has more accurately classified and identified the detection targets of the two categories.
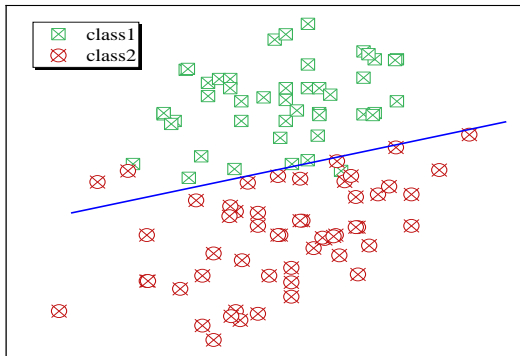


Fig. 10. Object classification prediction simulation.

## V. DISCUSSION

Obviously, the root filter model describes the overall characteristics of a person, and if only one model is used to detect objects, it is definitely not as effective as detecting multiple models. So DPM also has a component filter model, and the number and parts of the component filters can be designed by oneself. The component filters describe the local features of a person's head, hands, and feet.

The local feature position detected by the component filter must not be too far from the position of this local feature in the root filter. Imagine if the distance from the hand to the body is twice the height, then is this still a person. So DMP added the position offset between the component filter model and the root filter model as the offset coefficient. As shown in the spatial model in the figure, the center of each box naturally represents

the rational location of the component model. If the position of the detected component model happens to be here, the offset coefficient will be 0, and a certain value will need to be subtracted from the surrounding area. The further the deviation, the greater the value will be subtracted. That is to say, subtracting the offset coefficient from the comprehensive score essentially involves using the spatial prior knowledge of the root model and component model.

Compared with the traditional anchor idea, YOLOv3 mainly makes two improvements. First, the method of manually selecting bounding boxes in the conventional anchor idea is changed, and a more reasonable K-means clustering method is selected. Compared with the manual selection of bounding boxes, some tall, thin and short boxes appear in the boxes obtained after K-means clustering [19]. Although unsupervised feature selection can remove some irrelevant and redundant features in some cases, it is usually more difficult than supervised feature selection because it does not have class information to help determine which features are relevant [20]. During detection, the inner product of the DMP feature vector of the input image and the filter operator is calculated to obtain the response value of this filter operator. After comprehensive different filtration the response value of the wave operator can be calculated as a comprehensive score, and then trained as a score threshold to detect humans.

## VI. CONCLUSIONS

With the change and development of society, information technology has had a wide and profound impact on today's society. Making full use of modern information technology has become an objective trend of social development; as one of the overall goals of information construction, current personnel area monitoring and management system needs to combine advanced digital image processing technology, advanced computer information technology and exchange network technology to meet the needs of high reliability, stability, security and applicability. This study constructs an intelligent video analysis system based on the metaverse environment. The procedure takes the YOLOv3 model as the core and fine-tunes it to enhance its detection ability. Experiments show that the fine-tuned YOLOv3 model has been significantly improved.

From the perspective of model structure, the YOLOv3 model does not use pooling layers and fully connected layers, but instead sets the convolutional stripe to two to achieve downsampling. Every time this convolutional layer is passed, the size of the image will be reduced to half. However, mainstream systems such as Windows, MacOS, Linux, Android, iOS, and Chrome OS do not have such model structure characteristics. Secondly, in terms of setting prior boxes, YOLOv3's method uses K-means clustering to obtain the size of prior boxes. On the COCO dataset, YOLOv3 clustered a total of 9 sizes of prior boxes. These prior boxes are set based on different scales of image features, enabling the model to better adapt to target detection at different scales. However, this method is not adopted by mainstream systems. Combined with the development of intelligent video surveillance, pedestrian detection technology and deep learning at home and abroad, this research constructs a smart personnel

area management ad control system that meets the actual needs. The construction scheme covers both hardware and software. This study selects the hardware equipment suitable for this system and designs an appropriate layout scheme according to the actual situation on site. In terms of software, this study combines a data acquisition module, image management module, database storage and processing module and result display module to complete various intelligent management requirements. Although this research realizes the simultaneous detection of multiple video streams, the detection results of each video stream need to be more connected. In the future, we can combine the detection results of each video stream by using technologies such as Reid to form a more powerful system.

Competing of interests: The authors declare no competing of interests.

Authorship Contribution Statement: Dandan Wang: Writing-Original draft preparation, Conceptualization, Supervision, and Project administration. Tianci Zhang: Methodology, Language review, and Validation.

## REFERENCES

[1] G. B. Petersen, G. Petkakis, and G. Makransky, "A study of how immersion and interactivity drive VR learning," Comput Educ, vol. 179, p. 104429, 2022.

[2] H. Wu, T. Cai, D. Luo, Y. Liu, and Z. Zhang, "Immersive virtual reality news: A study of user experience and media effects," Int J Hum Comput Stud, vol. 147, p. 102576, 2021.

[3] J. Brade, M. Lorenz, M. Busch, N. Hammer, M. Tscheligi, and P. Klimant, "Being there again–Presence in real and virtual environments and its relation to usability and user experience using a mobile navigation task," Int J Hum Comput Stud, vol. 101, pp. 76–87, 2017.

[4] M. Davia-Aracil, J. J. Hinojo-Pérez, A. Jimeno-Morenilla, and H. Mora-Mora, "3D printing of functional anatomical insoles," Comput Ind, vol. 95, pp. 38–53, 2018.

[5] T. Kempitiya, S. Sierla, D. De Silva, M. Yli-Ojanperä, D. Alahakoon, and V. Vyatkin, "An Artificial Intelligence framework for bidding optimization with uncertainty in multiple frequency reserve markets," Appl Energy, vol. 280, p. 115918, 2020.

[6] K. Kanai, K. Ogawa, M. Takeuchi, J. Katto, and T. Tsuda, "Intelligent video surveillance system based on event detection and rate adaptation by using multiple sensors," IEICE Transactions on Communications, vol. 101, no. 3, pp. 688–697, 2018.

[7] C. Zhao et al., "Lung segmentation and automatic detection of COVID-19 using radiomic features from chest CT images," Pattern Recognit, vol. 119, p. 108071, 2021.

[8] H.-M. Hsu, J. Cai, Y. Wang, J.-N. Hwang, and K.-J. Kim, "Multi-target multi-camera tracking of vehicles using metadata-aided re-id and trajectory-based camera link model," IEEE Transactions on Image Processing, vol. 30, pp. 5198–5210, 2021.

[9] M. Uzair, R. S. A. Brinkworth, and A. Finn, "Bio-inspired video enhancement for small moving target detection," IEEE Transactions on Image Processing, vol. 30, pp. 1232–1244, 2020.

[10] Z. Zhao, X. Li, H. Liu, and C. Xu, "Improved target detection algorithm based on libra R-CNN," IEEE Access, vol. 8, pp. 114044–114056, 2020.

[11] S.-S. Baek et al., "Identification and enumeration of cyanobacteria species using a deep neural network," Ecol Indic, vol. 115, p. 106395, 2020.

[12] L. Zeng, B. Sun, and D. Zhu, "Underwater target detection based on Faster R-CNN and adversarial occlusion network," Eng Appl Artif Intell, vol. 100, p. 104190, 2021.

[13] H. Zhou, Y. Zhao, and W. Xiang, "Method for judging parking status based on yolov2 target detection algorithm," Procedia Comput Sci, vol. 199, pp. 1355–1362, 2022.

[14] L. Cai, F. Dong, K. Chen, K. Yu, W. Qu, and J. Jiang, "An FPGA based heterogeneous accelerator for single shot MultiBox detector (SSD)," in 2020 IEEE 15th International Conference on Solid-State & Integrated Circuit Technology (ICSICT), IEEE, 2020, pp. 1–3.

[15] A. Gavriilidis, J. Velten, S. Tilgner, and A. Kummert, "Machine learning for people detection in guidance functionality of enabling health applications by means of cascaded SVM classifiers," J Franklin Inst, vol. 355, no. 4, pp. 2009–2021, 2018.

[16] C. Banerjee, T. Mukherjee, and E. Pasiliao Jr, "An empirical study on generalizations of the ReLU activation function," in Proceedings of the 2019 ACM Southeast Conference, 2019, pp. 164–167.

[17] G. Wang, G. B. Giannakis, and J. Chen, "Learning ReLU networks on linearly separable data: Algorithm, optimality, and generalization," IEEE Transactions on Signal Processing, vol. 67, no. 9, pp. 2357–2370, 2019.

[18] D. Wu et al., "Lameness detection of dairy cows based on the YOLOv3 deep learning algorithm and a relative step size characteristic vector," Biosyst Eng, vol. 189, pp. 150–163, 2020.

[19] Z. Feng, W. Niu, R. Zhang, S. Wang, and C. Cheng, "Operation rule derivation of hydropower reservoir by k-means clustering method and extreme learning machine based on particle swarm optimization," J Hydrol (Amst), vol. 576, pp. 229–238, 2019.

[20] H. Hu, R. Wang, X. Yang, and F. Nie, "Scalable and flexible unsupervised feature selection," Neural Comput, vol. 31, no. 3, pp. 517–537, 2019.

# An Evaluation Method of English Composition Automatic Grading Based on Genetic Optimization Algorithm and CNN Model

Li Wang

School of Foreign Studies, Henan University of Urban Construction, Pingdingshan 467000, China
University of the Cordilleras, Baguio City,2600, Philippines

*Abstract*—In response to the problems of traditional genetic algorithms in evaluating English compositions, the stability of automatic grading of English compositions has been further enhanced. This article evaluates the teaching effectiveness of automatic grading of English compositions using an optimization fusion algorithm combined with genetic optimization algorithm and CNN model. By analyzing genetic content and optimization algorithms, a corresponding fusion optimization model was obtained, and the automatic evaluation of English compositions was analyzed and predicted through experimental verification. The results indicate that the curves corresponding to different parameters exhibit typical segmentation features through the variation curves of individual numbers under different scale factors. And through quantitative description and analysis of the curve, it can be seen that the change in proportion factor has an absolute advantage in the impact of genetic algorithm on the number of children. As the number of samples increases, the performance of genetic optimization algorithms under the f function shows an upward trend. Research has shown that the writing content index has the greatest impact on English writing, while the corresponding grammar errors have the smallest impact on English writing. Finally, the accuracy of the optimized model was verified by comparing the model curve with experimental data. This study provides theoretical support for the use of genetic optimization algorithms and CNN models in English, and provides ideas for the use of optimization algorithms in other fields.

*Keywords*—*Genetic optimization algorithm; CNN model; English composition; Automatic scoring; Teaching effect*

## I. INTRODUCTION

Researchers have proposed various evaluation methods for the quality of English teaching in universities, such as grey relational analysis and fuzzy comprehensive evaluation [1]. However, these methods are suitable for linear models and are difficult to adapt to nonlinear teaching quality evaluation problems. They have subjective and random defects and cannot effectively achieve teaching quality evaluation. In terms of natural language processing models, researchers mainly use neural network-based models and convolutional neural network-based models. These models can convert text information into vectors and perform part of speech analysis, word form restoration, and other processing to ultimately obtain a feature vector related to text information [2]. In terms of scoring algorithms, researchers mainly used machine learning based algorithms and deep learning based algorithms.

Among them, machine learning based algorithms mainly improve the accuracy of prediction by training models [3]. The algorithm based on deep learning mainly falsely optimizes the structure and weight of the neural network to improve the accuracy of prediction [4]. The evaluation of teaching quality for university teachers is an important way to improve teaching management level and teaching ability of teachers. By utilizing teaching quality evaluation, students can provide feedback on the teacher's teaching situation, and teachers can reflect on the teaching effectiveness. Schools can effectively implement teaching management improvements and provide targeted training for teachers. English teaching is an important part of higher education, and the evaluation process of English teaching quality is relatively complex. Therefore, constructing an objective and scientific evaluation model for English teaching quality is a hot research direction [5]. Given the problems existing in chemical reactions, genetic optimization algorithm was used to improve the accuracy of chemical reduction reactions [6]. Firstly, the chemical reaction data were imported into the optimization model, and then the characteristic parameters of the test data were derived through further analysis of the model. Finally, the optimized model was used to modify the derived information. To verify the correctness of the model, relevant experiments were applied to verify and analyze the results of chemical reactions. In order to further improve the quality of tea, the traditional genetic algorithm can be optimized to reflect and describe the relevant properties of tea [7]. Different evaluation indexes can be obtained by extracting the characteristic parameters of tea leaves. Through the arrangement and analysis of the evaluation indexes, the optimized index data can be obtained, and the quality of tea can be judged through the analysis of the data. Finally, a large number of data were used to evaluate the correctness of the model. The convolutional neural network also has applications in various domains: Aiming at the issues of rock identification, the convolutional neural network can be modified to obtain the optimized convolutional neural network. The optimization model can better identify and analyze the rock [8]. The corresponding influencing factors can be found by extracting the rock's data features. Thus, the variation curves of rock characteristics under different influencing factors were obtained. Experiments were carried out to verify the model. The results show that the model can describe the characteristic parameters of rock well. Convolutional neural networks can also play a greater role in medical monitoring [9]. Specific medical parameters can be obtained through scanning

and extracting samples, different etiologies can be studied through description and analysis, and accurate results can be finally obtained.

Lightweight encryption (LWC) is an emerging technology used to develop encryption algorithms or protocols for implementation in restricted environments, such as WSNs, RFID tags, smart medical devices, and many other embedded systems. It is expected that LWC will play an important role in ensuring the Internet of Things and universal computing. The term 'lightweight' can be considered from two perspectives, namely hardware and software. However, portability in hardware does not necessarily mean portability in software, and vice versa. The above studies were mainly from medicine, architecture, and so on, but applying genetic algorithms in English composition was relatively rare. To further improve the application of the genetic algorithm and CNN model in English composition evaluation, based on the genetic theory, the fusion optimization model of the genetic algorithm and CNN theory was adopted to study the automatic scoring of English composition. The evaluation rules of scoring effects under different factors were obtained by analysing English composition's characteristics and related indicators. Eventually, the accuracy of the model was confirmed by associated experiments. This optimization model can improve the research ideas for applying genetic optimization algorithms and the CNN model in other fields.

This article optimizes the problems that exist in traditional evaluation of English compositions. The research has the following innovations:

*1)* The method proposed in this article is suitable for linear models and for teaching quality evaluation problems with nonlinearity. It solves the defects of subjectivity and randomness, and can effectively achieve teaching quality evaluation.

*2)* The corresponding fusion optimization model was validated through experiments to analyze and predict the automatic evaluation of English compositions.

As the number of samples increases, the performance of genetic optimization algorithms under the f function shows an upward trend. The curve corresponding to the g function is stable.

Section I analyzes the relevant background of automatic grading and evaluation of English compositions using genetic optimization algorithms and CNN models. Section II analyzes the relevant theories of genetic optimization algorithms. Section III further analyzes and understands the computational process and structural unit of convolutional neural networks. By organizing and analyzing relevant data, a convolutional neural network structure diagram was drawn. Section IV elaborates on the application of genetic optimization algorithms and CNN models in English writing, and analyzes the basic content of the evaluation method for the teaching effectiveness of automatic grading of English writing. The model curve in Section V indicates that the optimized model can effectively illustrate and characterize the trend of changes in English composition indicators. Therefore, in order to study

the impact of automatic grading of English compositions on teaching, an optimization model can be used.

## II. RELATED THEORY OF GENETIC OPTIMIZATION ALGORITHM

A biological individual is considered a response to the optimization algorithm in a genetic algorithm, a random search algorithm [10]. The population, which consists of many individuals, is the algorithm's solution set. Next, the weaker individuals are continuously eliminated through genetic processes like selective crossover and mutation. The genes with the favorable mutation are passed on to the next generation through probabilistic choice. The output individual is the ideal one that endures after screening when the termination condition is reached after continuous iteration. Both discrete and continuous optimization problems can be solved using the genetic algorithm, which is simple to use. Its multi-direction global optimization performance has good theoretical value for addressing challenging optimization problems today.

The existing cryptography relies on mathematical algorithms and key size, which can take decades to hundreds of years to crack. In theory, quantum computing can break existing encryption faster, possibly within days or even minutes. PQC is a new encryption method that resists quantum computing attacks by using very difficult mathematical problems that quantum computers cannot solve in a reasonable amount of time.
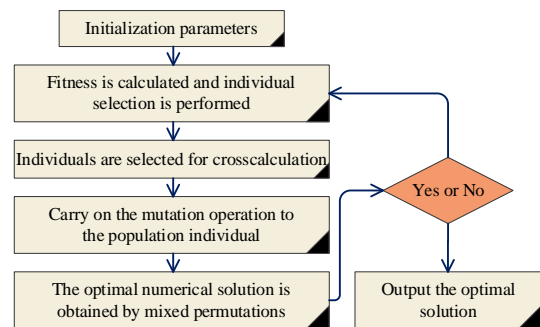


Fig. 1. Genetic algorithm solution flow chart.

Side channel attack is a cryptographic analysis method that uses information other than the encryption algorithm itself to infer certain information in the encryption algorithm, which may lead to the leakage of encrypted data. Power analysis uses the changes in power consumption during the encryption process to derive the state of the encryption algorithm and then crack the key. Time analysis uses the execution time differences of different encryption operations to infer the internal state of the encryption algorithm. Lightweight cryptography is a cryptographic method targeting resource constrained environments such as IoT devices, mobile devices, and embedded systems. Due to the limited computing power, storage resources, and energy supply in these environments, lightweight cryptography requires less computational and storage resources, while ensuring the security and integrity of encrypted data. To analyze the solving process of the genetic optimization algorithm, it summarized and analyzed different genetic algorithms and thus obtained the flow chart of genetic

optimization calculation under other algorithm theories as shown in Fig. 1. Considering the calculation process in the figure, initialization analysis should be carried out on relevant data first, making the study results more accurate. Initialization parameters include population size, iteration times, etc. The features of parameters can be extracted through initialization, and then the extracted feature parameters can be imported into the next calculation. In the next step, individuals can be selected through fitness calculation to obtain optimized genetic optimization data. Then, it is imported into the genetic optimization algorithm for cross-calculation, and the characteristics of the population are optimized and modified through cross-calculation. Then, the relevant data of population quantity are imported into the variation feature module for mutation operation, and then the data obtained from mutation operation are mixed and arranged, and the optimal number solution is obtained through calculation. Finally, judge whether the termination condition is met. If not, further iterative analysis is required. If so, the data will be output.

### A. Genetic Algorithms

Genetic algorithm is an optimization algorithm that simulates the process of biological evolution. It seeks the optimal solution by simulating processes such as gene combination, crossover, and mutation. In networks that require multi-agent management, genetic algorithms can be used to optimize transmission quality. For example, by simulating the interaction and competition process between agents in a network, genetic algorithms can automatically find an optimal network transmission strategy [11]. The process of using a genetic algorithm mainly involves two aspects such as cross-real number recombination and mutation [12], [13]. (1) Crossover and recombination of real numbers: the commonly used methods mainly include discrete and intermediate recombination in the recombining real numbers.

*1) Discrete recombination*: The operation of discrete recombination is relatively simple; that is, the genes on the above individuals before optimization are equally probabilistic and randomly inherited into the optimized individuals to realize individual renewal.

*2) Intermediate recombination*: The intermediate recombination completes the individual update process by calculating the expression as follows:

$$X = X_1 + a(X_2 - X_1) \tag{1}$$

X represents the child produced, $X_1$ and $X_2$ are the two selected parents, and a is the scaling factor.

Different scale factors influence the number of individuals in the genetic algorithm. To evaluate the influence of scale factors on the number of individuals, it draws the change curves of the number of individuals under different scale factors. Fig. 2 reveals that the number of individuals of the scale factor corresponding to additional parameter a shows different variation trends, as shown below: When a=-1, the corresponding curve shows typical two-stage variation features. In the first stage, the curve shows a gradual decline as the number of iterative steps increases, and the curve slope indicates that the curve at this stage is linear. However, when the number of iterations exceeds 60, the corresponding curve

manifests an approximate constant trend of change, indicating that the number of sub-individuals decreases gradually with the increase of the number of iterations. A two-stage variation trend is still visible in the corresponding curve when parameter a equals to 1. With more iterations in the first stage, the curve gradually gets better. As opposed to this, the slope of the corresponding curve is greater than that of the parameter a = -1, demonstrating that the influence of the parameter a = 1 on the number of sub-individuals is greater than that of the parameter a = 1. The corresponding curve shows a slight or gradual decline when the number of iterations exceeds 60. The overall curve thus demonstrates that when parameter a = 1, the influence of the number of corresponding sub-individuals still affects the change in volatility as a whole. When a=0, the associated curve exhibits a trivial change trend, and when its scaling factor is greater than 60, the related curve shows a slight growth trend. The number of sub-individuals under the three parameters above demonstrates that the influence of neutron individual numbers has a clear advantage in changing the scale factor. Therefore, when calculate the scale factor of the genetic optimization algorithm, it need to consider the specific variation of parameters.
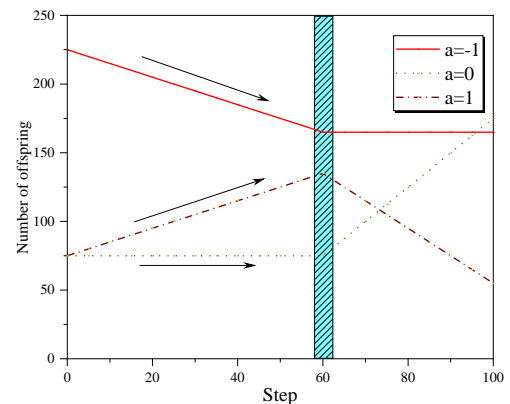


Fig. 2. Scale factor variation diagram.

*3) Variation*: Variation refers to the change of some genes in the calculation process of the genetic optimization algorithm so that the characteristics of the number of offspring are different from those of other individuals. The variation of the genetic optimization algorithm can be divided into real number variation and binary variation according to separate research contents and calculation methods.

*a) Real number variation*: The following formula is generally used for real number variation.

$$X_3 = X \pm 0.5L\Delta \tag{2}$$

$$\Delta = \sum_{i=0}^{m} \frac{a(i)}{2^i} \tag{3}$$

$X_3$ is the individual after mutation, and L is the value range of the variable. $\triangle$ is the coefficient of variation, m is an artificially set integer, and a (i) is the probability function.

*b) Binary Variation*: Binary variation is relatively simple. For the binary code of characters, several positions are randomly selected on the individual gene sequence first, and then the gene values on these loci are reversed.
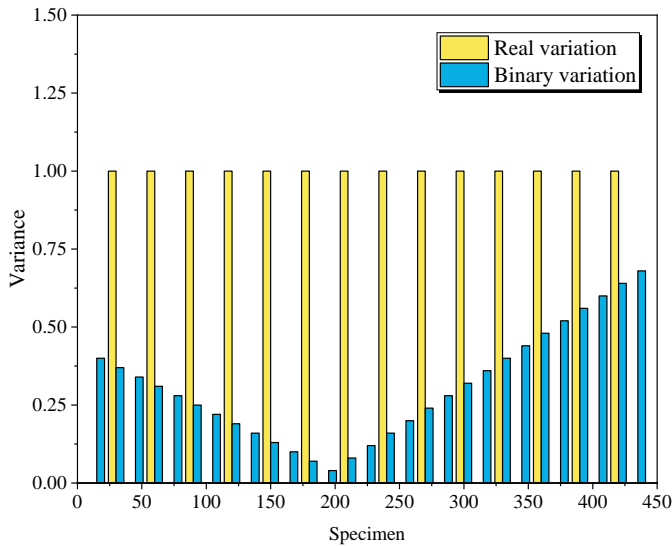
Fig. 3.    Diagram of changes of two variation indicators.

Through variation calculation, it can see that different calculation methods have other influences on the number of variations. To study the effect of real number variation and binary variation on the number of variations, the change curves under two variation indicators were drawn, as shown in Fig. 3. As the figure displays, with the gradual increase in the number of samples, the two different variation modes show typical variation trends. Firstly, it can be seen from the real number variation method that the real number variation shows a distinct piecewise change as the number of iterations increases. When the number of samples is odd, the corresponding sample variation is 1. When the corresponding variation sample reaches an even number, the corresponding sample variation is zero. Therefore, the real number variation shows the typical characteristics of the 01 variation. As can be seen from the curve corresponding to the binary variation method, when the variation gradually increases, the corresponding number of variations shows a gradual decline, and the slope of the curve corresponding to the downward trend is approximately constant. When the number of samples exceeds 200, the corresponding curve gradually increases. Through the above analysis, it can see that binary variation shows different trends with different sample numbers. Therefore, relevant studies show that to improve the accuracy of the genetic optimization algorithm, it is necessary to use a wide range of samples for iteration and analysis.

### B. Genetic Algorithms Update Content

It can be seen from the above research that the genetic algorithm conducts targeted research on input data through real number variation and binary variation and finally outputs neurons through an iterative updating calculation method [14], [15]. Therefore, the individual update method can be adopted to optimize the genetic algorithm, and the corresponding optimization and update steps are as follows:

*1) Determine the neural network of the genetic algorithm*: To solve the neuron j corresponding to the initialisation data of the optimization problem and the corresponding weight

vector $W_j$, the connected structural network of the genetic algorithm should be adopted [16], [17].

*2) Select individual samples from the individuals:* Produced by the genetic algorithm as input data into the genetic algorithm structural network. The corresponding calculation formula is as follows:

$$\text{dis}(W_j, X_t) = \sqrt{\sum_{k=0}^{k=n}(w_j^k - x_j^k)^2} \qquad (4)$$

where is the gene value at the kth position on the j-th neuron, $x_j^k$ represents the gene value at the kth position on the i-th individual, and $X_t$ is the sample vector.

*3) Solve the best matching unit*: determine the relationship and distance between the genetic algorithm data in the above way, and find the neuron data with the closest distance.

*4) Calculate the neighborhood radius of the neuron*:

$$\begin{cases} \sigma = \sigma_0 \exp(-t/\lambda) \\ \lambda = N_0 / lg(\sigma_0) \end{cases} \qquad (5)$$

Where is the initial field radius; $\lambda$ is the time constant?
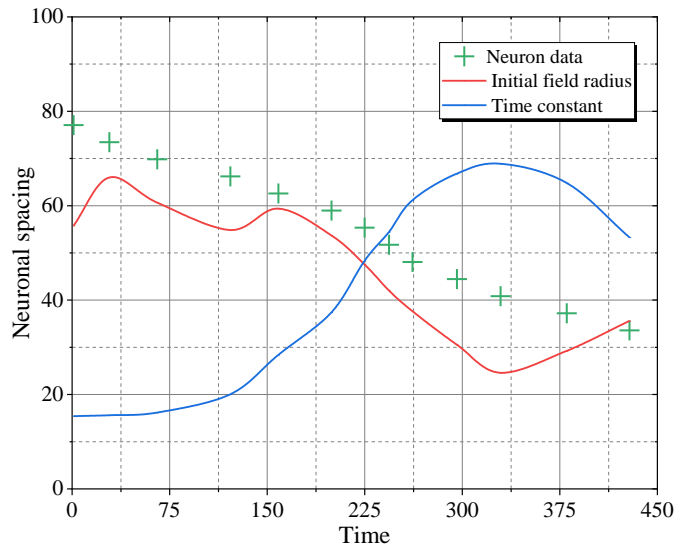


Fig. 4.    Effect of the coefficient on neuronal spacing.

According to the above formula and analysis, it can be seen that the specific parameters of neurons greatly influence the spacing of neurons, and the different parameters will lead to differences in the calculation methods and theories of the spacing of neurons. To study the influences of two factors on neuron spacing, it drew the variation curves of neuron spacing of the genetic optimization algorithm under two parameters, as shown in Fig. 4. It can be seen from the curves that the variation trend of neurons under two different parameters presents typical nonlinear changes. In contrast, the corresponding neuron curve shows a gradual downward trend. Moreover, it can be seen from the slope that the linear characteristics of neuron data are obvious. Specifically, first of all, it can see through the initial field radius curve rise gradually. The linear decline, when it reaches the minimum spacing of neurons and shows the increasing trend, gradually

declines, then hits the stage when it rises again, showing the typical volatility change trend. As shown in the influence curve of the time constant, the corresponding curve first exhibits a stable change trend as time increases gradually, and then the corresponding curve gradually increases. And when it reaches its highest point, the corresponding curve slowly decelerates. The slope of the corresponding curve also exhibits a gradual increase trend. The overall data feature of the curve with time parameter has the comprehensive effect of linear and nonlinear. Therefore, it must comprehensively consider the impact of the initial domain radius and time constant on neuron spacing.

*5) Solve the neuron update formula*: Through the above analysis and solution, the influence of parameters on the spacing between different neuron data can be obtained, and the corresponding update formula is as follows:

$$w_j^k(t+1)=w_j^k(t)+L(t)\theta(t)(x_j^k(t)-w_j^k(t)) \quad (6)$$

where is the gene value at the position after the update, is the learning speed factor, and is the best Euclidean distance?

*6) Determine whether the termination conditions are met*: The neuron data are compared by setting the termination conditions of the corresponding predictive optimization algorithm.

*7) Update individual data and location information*. The corresponding update formula is as follows:

$$X=w^* + \sum_{k=0}^{m-1} a_j^k U_j^k + N(0,\sigma I) \quad (7)$$

Where represents the best matching unit with the individual; $a_j^k$ is the Euclidean distance between adjacent spirit longitude elements; $U_j^k$ is the unit vector of adjacent neurons; m is the number of targets; $U_j^k$ is a normally distributed noise vector; I am the identity matrix.

For analyzing the impact of various parameters in the update formula on the updated data of the genetic optimization algorithm, relevant data were obtained through iterative calculation. The influence curves of four different parameters on the genetic algorithm were drawn, as shown in Fig. 5. Different parameters exhibit typical variation characteristics, as can be seen in the figure. As can be seen, the updated data for the corresponding parameter a shows a trend of slow increase with the gradual increase of iteration times and time. However, a slight nonlinear variation can be seen on the corresponding fitting curve. As shown by the parameter U, the curve initially declines gradually. When there are more than four iterations, the corresponding appropriate curve initially shows a nonlinear change before fluctuating and exhibiting a sharp downward trend. It can be seen from parameter m that the overall curve remains at about 70, indicating that parameter m has the least influence on genetic algorithm update. Still, it also shows that the parameter has a relatively clear specific value of genetic algorithm update and good corresponding stability. It can be seen from parameter I that the curve shows typical linear characteristics, the corresponding quasi-sum curve has obvious smoothness, and the corresponding data presents a trend of a gentle rise. Through the above analysis, various parameters have different influences on the genetic algorithm, and it is necessary to select specific parameters according to the actual situation to analyze the genetic optimization algorithm to acquire precise outcomes.

*C. Test Function Selection of Genetic Optimization Algorithm*

Since the complexity of optimization problems affects the computational efficiency of swarm intelligence algorithms [18], [19], it is necessary to select four commonly used test functions, and their corresponding forms are shown as follows:

*1) Test function f(x)*: Test function f(x) is an optimised test function with a simple structure consisting of two variables and a constraint condition.

$$f(x)=x_1 + (x_2\text{-}1)^2 \quad (8)$$

*2) Test function g(x)*: This function is a test function of multidimensional single constraint conditions.

$$g(x) = (\sqrt{n})^n \prod_{i=1}^n x_i \quad (9)$$

*3) Test function h(x)*: Test function H (x) is a low-dimensional multi-constraint single-objective optimization problem.

$$h(x) = \frac{\sin^3(2\pi x_1)\sin^2(2\pi x_2)}{x_1^3(x_1+x_2)} \quad (10)$$

*4) Test function k(x)*: This function is a multi-dimensional and multi-constraint complex nonlinear optimization problem, which is representative of verifying the algorithm's feasibility.

$$k(x) = (x_1 - 10)^3 + 5(x_2 - 12)^2 + x_3^4 + 3(x_4 - 10)^2 \quad (11)$$

It can be seen from the above analysis that genetic optimization algorithms contain different test functions, and the other test functions lead to different solving processes and methods for nonlinear problems of genetic algorithms. To analyze the influence of the four tests performs on the performance of the genetic algorithm, the variation curves of the genetic optimization algorithm under different samples were obtained by summarizing the data, as revealed in Fig. 6. Regarding the change curve in the figure, it can be seen that the performance of the corresponding genetic optimization algorithm shows a gradually increasing trend with the gradual growth of the number of samples of the f function. However, when the number of samples is about 65, the corresponding genetic optimization performance data shows a sudden decline because when the number of samples is 65, the corresponding calculation method will further propose the characteristics of this parameter. As a result, the corresponding genetic optimization performance index has declined. From the change rule of g performance, it can be seen that the corresponding bar chart has a constant adjusted trend. And the slope is the same up and down. It shows that the genetic optimization performance of the g function is stable. It can be seen from the change of the h function that the corresponding genetic optimization performance index decreases gradually from the maximum to the minimum, which indicates that the data of the genetic optimization performance corresponding to this function has a large fluctuation, showing a trend of gradual decline. Finally, it can be seen from the change of the k

function that the corresponding data index shows an incremental improvement. When the corresponding data reaches the maximum, it indicates that the data of the genetic optimization algorithm of the corresponding k function shows a gradual increase trend of change.
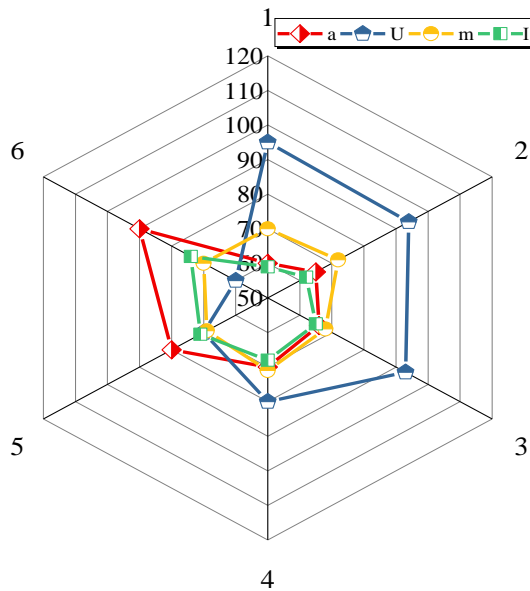


Fig. 5. Influence of different parameters on genetic algorithm update.
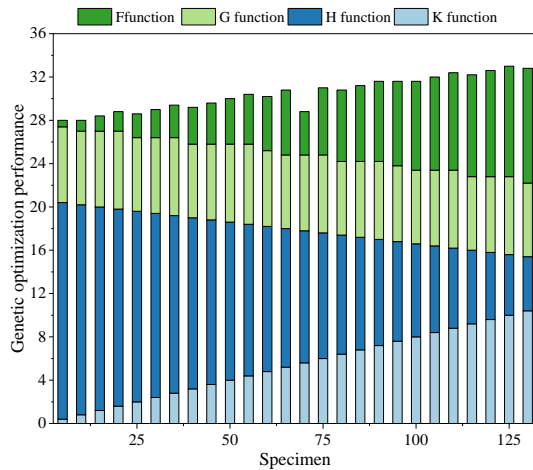


Fig. 6. Test function variation diagram.
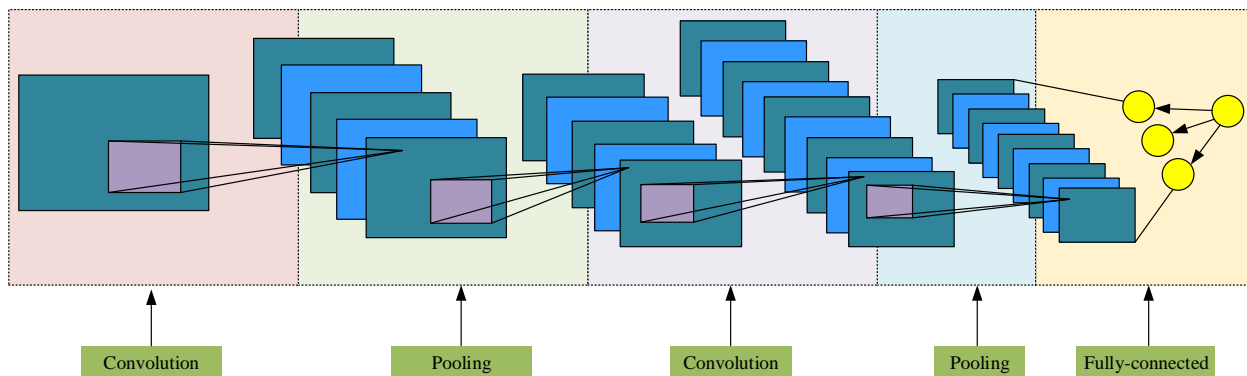
## III. CNN MODEL

A convolutional neural network is a typical structure of artificial neural networks, which has the characteristics of local connection, weight sharing and pooled sampling and has gradually become a representative network for feature extraction in deep learning networks [20], [21].

To further analyze and understand the convolutional neural network's computation process and the structural unit, the convolutional neural network, the structure diagram of the convolutional neural network was drawn by sorting out and analyzing relevant data, as shown in Fig. 7. It can be seen from relevant studies that convolutional neural networks can be divided into five modules according to different research contents and methods; corresponding contents mainly include the convolution layer, pooling layer and full connection layer. In the corresponding computing module of the convolutional neural network, the model data is first imported into the specific computing module. Then the data features are analyzed and processed by further data feature extraction module. The optimised results are output through data optimization and modification analysis, and experimental data further verify the optimized data. Thus, the optimized convolutional neural network calculation results are obtained. The main calculation steps of the convolutional neural network are as follows:

*1) Similarity measurement and analysis*: In the similarity measurement process of the convolutional neural network, the correlation distance formula is widely used in similarity measurement, and the corresponding procedure is shown as follows:

$$d(\text{x,y}) = \left(\sum_{i=1}^{n} \left|x_i \text{-} y_i\right|^p\right)^{1/p} \qquad (12)$$

where x and y respectively represent the vector representation of two image samples, n represents the length of the vector representation, and p is a constant.

The similarity measurement method of the i-th element can be measured as follows:

$$z_i = \frac{1}{h \times w} \sum_{i=1}^{h} \sum_{j=1}^{w} F(\text{i,j}) \qquad (13)$$

where h represents the height of the feature graph, w represents the width of the feature graph, and F represents the channel of the feature graph.



Fig. 7. Structure diagram of convolutional neural network.

*2) Sample generation*: When the directional pin-mixing augmented method is used to analyze the genetic optimization algorithm, the corresponding implementation process is shown as follows:

$$\begin{cases} \text{I}=(1-\text{M}_\lambda) \odot I_m + \text{M}_\lambda \odot I_m \\ \text{y}=\lambda\text{y}_m + (1-\lambda \times y) \end{cases} \qquad (14)$$

where I represent sequence mixing and y represents sequence category label. Describes the specific gravity of data, I'm representing the sequence of training samples, and $y_m$ represents the sequence of category tags. It is the dot product operation.

*3) Training sample evaluation*: In data recognition of convolutional neural network, classification accuracy R is generally used as the evaluation result, and the corresponding formula is shown as follows:

$$R=\frac{I_r}{I} \qquad (15)$$

$I_r$ represents the data quantity of classification, and I represent the data quantity of total evaluation.

To analyze the influence of convolutional neural network with accuracy index, the accuracy change curves under different iterations and accuracy index were drawn through experimental analysis, as shown in Fig. 8. The research shows that the accuracy index and rate are typical two-stage

structures. In the first stage, the corresponding accurate index $I_r$ shows a trend of gradual decline. And its slope remains constant, indicating that the data of the precise index shows a linear change characteristic, while the same accurate total I show a gradually increasing trend with the increase of the number of iterations. This is because the accuracy index increases with the rise of characteristic parameters corresponding to the number of iterations, leading to an increase in calculation results. It can see an obvious trend of gradual decline through the curve of the corresponding accuracy R. This indicates that when the number of iterations is from 0 to 100, the corresponding accuracy rate decreases gradually with the increasing number of iterations. In the second stage of the curve, with the further increase in the number of iterations, the corresponding accurate index shows the same linear change. It belongs to the evolution of linear increase. The total number of corresponding indicators declined rapidly with the rise in iteration times, and the corresponding downward trend showed an obvious linear decline. As can be seen from the accuracy curve, with the increase in the number of iterations, the related accuracy shows a gradually increasing trend. This indicates that when the number of iterations exceeds 100, the accuracy of the connected convolutional neural network gradually improves. Therefore, in the actual use and calculation process, it needs to iterate and calculate the genetic optimization algorithm and convolutional neural network many times so as to obtain more accurate results.
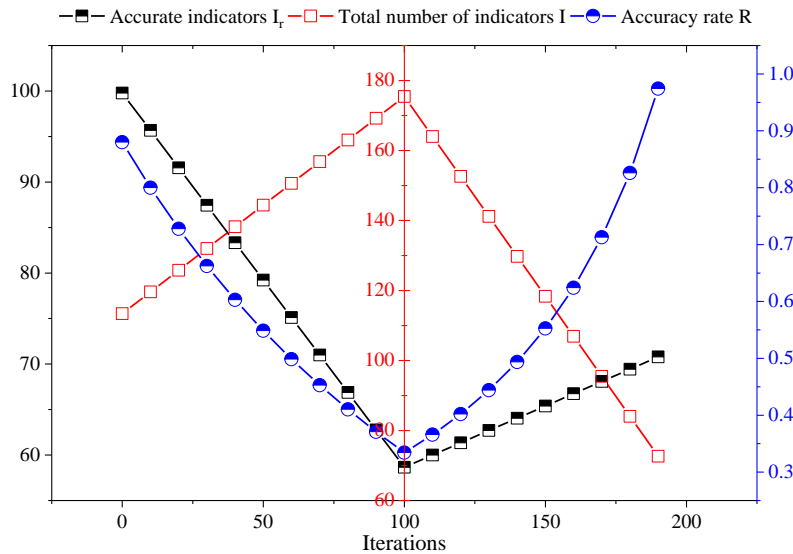


Fig. 8.   Change in accuracy chart.

## IV. APPLICATION OF GENETIC OPTIMIZATION ALGORITHM AND CNN MODEL IN ENGLISH COMPOSITION

### A. The basic Content of English Composition Automatic Grading Teaching Effect Evaluation Method

English composition is very important for English teaching and assessment. Still, there are a series of problems in the practical application of English composition evaluation, mainly including: (1) English composition scoring efficiency is low: In the useful application process, the efficiency of English

composition is low because of the artificial evaluation. (2) The standard of English composition scoring is not unified: There is no unified standard for English composition evaluation, which is greatly influenced by human factors in the actual evaluation process, resulting in the corresponding English composition evaluation results are not unified. (3) Single evaluation method for English compositions: English compositions are analyzed by single evaluation index in the evaluation process, resulting in the corresponding evaluation results are too single.
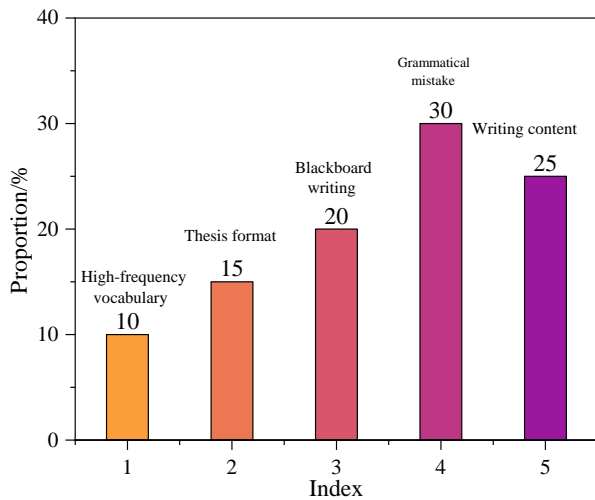
Fig. 9. English composition automatic scoring index distribution map.

To further analyze the influence of different indicators of automatic English composition scoring on English teaching effect, five various indicators are obtained through statistical analysis, including 1) high-frequency vocabulary, 2) composition format, 3) blackboard writing, 4) grammatical errors and 5) writing content, to analyze further the problems existing in self-scoring of English composition, the distribution chart of the comprehensive scoring index of English composition was obtained by summarizing and analyzing different data, as shown in Fig. 9. Regarding the results in the figure, the proportion of grammatical errors is the highest (30%), the content of writing is 25%, the handwriting on the blackboard is 20%, the composition format is 15%, and the proportion of high-frequency words is the lowest (10%). The original CNN neural network has a high accuracy in evaluating the quality of English teaching, both exceeding 81%. However, the evaluation accuracy of genetic algorithm optimized CNN neural network is better than that of the original CNN neural network The statistical results show that in the test samples, the genetic algorithm optimized CNN neural network model has an evaluation accuracy of more than 90%,. And some of the group evaluations have accuracy greater than 93%, indicating that the model has high approximation accuracy.

To further test the performance of the CNN neural network based on genetic algorithm optimization for English teaching quality evaluation constructed in this article, it is compared with the GA-BPNN evaluation model and the support vector machine (SVM) based evaluation model for performance testing. The simulation data remains unchanged.The experimental results show that the genetic algorithm optimized CNN neural network model constructed in this paper has high evaluation accuracy and operational efficiency This is because there is overfitting in the BP neural network in the GA-BPNN evaluation model, which affects the accuracy of the evaluation. In the SVM evaluation model, there are too many evaluation indicators, which interfere with each other, affecting the accuracy of the evaluation and increasing the computational cost.

## B. Results

The above analysis and research show many problems applying the teaching effect of automatic scoring English composition. According to the related theory of genetic algorithm, a new optimization model is adopted to evaluate and analyze the teaching effect of automatic scoring of English composition based on the genetic optimization algorithm and CNN algorithm to further analyse the indicators related to automatic scoring of English composition. Thus, the flow chart of automatic scoring of English composition under the combined action of the genetic optimization algorithm and CNN model is obtained, as shown in Fig. 10. The specific calculation process is as follows: First of all, the basic calculation parameters of the genetic optimization algorithm and CNN fusion model are also set, and then relevant imported data are extracted specifically to obtain different types of data features. Then the automatic scoring scheme of English composition is analyzed and determined according to the various data characteristics. Then the relevant English data is imported into other genetic optimization algorithm calculation modules on the basis of determining the scheme. It may be divided into three diverse modules, and the contents of each type of module are basically the same, including data import, extraction of corresponding parameters, update of English indicators, discrimination of corresponding standards and output of final results. The data calculated by different modules are imported into the final local termination condition, and the data can be decided whether to continue the iteration or directly output the results through the discrimination of the termination condition.

By adopting the fusion optimization model of the genetic optimization algorithm and CNN model calculation method, the evaluation analysis diagram of the automatic scoring teaching effect of English composition under different indexes was finally obtained, as shown in Fig. 11. It can be seen from the variation trend of other indicators in the figure that the increase in time greatly influences the proportion of indicators. The specific changes are as follows: With the gradual increase of high-frequency words over time, the proportion of the corresponding English composition index displays a slight decline, and the nonlinear characteristics of this trend are obvious. This indicates that the influence of high-frequency words on the evaluation effect of English compositions is relatively simple, and this index cannot be used only to evaluate and analyze English compositions. With the increase of time, the corresponding composition format shows a fluctuating change; that is, it increases slowly at first and then decreases gradually. The writing index on the blackboard shows a relatively stable trend at different times, which indicates that the writing index is less affected by time, indicating that this index is an inherent attribute of English composition, which can be used to evaluate the teaching effect of English composition scoring under the genetic optimization algorithm and CNN model. The variation trend of grammatical errors is basically the same as that of blackboard writing. Still, the corresponding data is less than that of blackboard writing, indicating that grammatical errors' influence on English composition is less than that of blackboard writing. Finally, through the specific content index of the paper, it can be seen that with time, the proportion of English composition as a

whole shows a gradually increasing trend. And the corresponding data are higher than the related data of other indicators in the same period. This indicates that the writing content index influences English writing most among all indicators.



Fig. 10. English composition scoring flow chart based on genetic optimization algorithm model.



Fig. 11. A summary graph of automatic scoring of English composition based on genetic optimization algorithm and CNN model.

## V. DISCUSSION

Genetic optimization algorithm is an optimization algorithm that mimics natural selection and genetic processes, and can find the optimal solution by iteratively optimizing the objective function. In automatic grading of English compositions, genetic optimization algorithms can be used to optimize grading standards and rules to better meet practical teaching needs and English language characteristics. Convolutional neural networks (CNN), as a deep learning model, are suitable for processing data such as images and text. In the automatic grading of English compositions, the CNN model can be used to automatically correct English compositions, achieving automated grading by learning a large amount of English composition sample data. The combination of genetic optimization algorithm and CNN model can first optimize the grading rules of English compositions using genetic optimization algorithm, and then automatically grade English compositions using CNN model. This combined method can fully leverage the advantages of both and improve the effectiveness and accuracy of automatic grading of English compositions.

Neural networks can be used to learn and predict the QoS of a given service combination. Historical data can be used for training, and then this model can be used to predict the QoS of new service combinations. Genetic algorithms can be used to find service combinations that meet certain QoS requirements. This may involve encoding services (such as using genetic coding), and then finding service combinations that meet QoS requirements under the predictive guidance of neural networks [22]. In QoS aware service composition, multiple service quality indicators need to be considered, such as processing time, throughput, latency, etc. By calculating the skyline, it is possible to find the optimal SFC that meets multiple QoS indicators simultaneously in a set of candidate service node combinations. Genetic algorithm is an optimization algorithm that simulates natural selection and genetic processes, suitable for solving the optimal solution of complex problems. In the process of combining service function chains, genetic algorithms can be used to generate initial solutions and perform selection, crossover, and mutation operations on the solutions to continuously optimize the quality of the solutions [20]. Correlation analysis and research show that the genetic optimization algorithm and CNN model can jointly evaluate the teaching effect of English composition automatic scoring better. In addition, relevant data show that different evaluation indexes impact English writing differently. To further verify the influence of the genetic optimization algorithm and CNN model on evaluation indexes of English writing. The validation and prediction curves of the optimization model are drawn, as shown in Fig. 12.

It is seen from the curve changes in the figure, the data on English composition increases linearly at first and then slowly decreases with the number of steps. Model curve presents that the optimization model can well elaborate and represent the changing trend of English composition indicators, so to investigate the impact of automatic English composition scoring on teaching, use the optimization model.
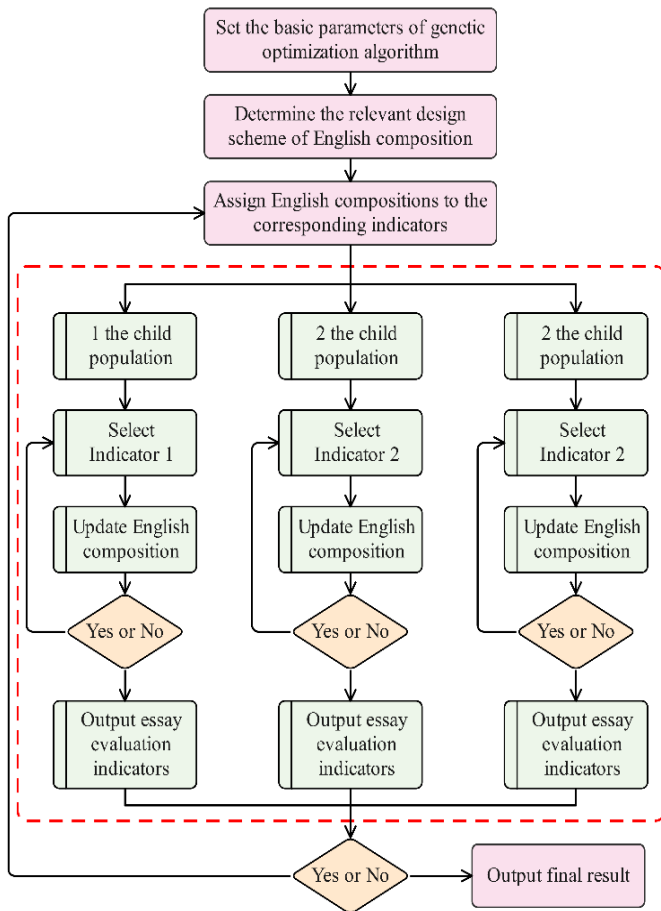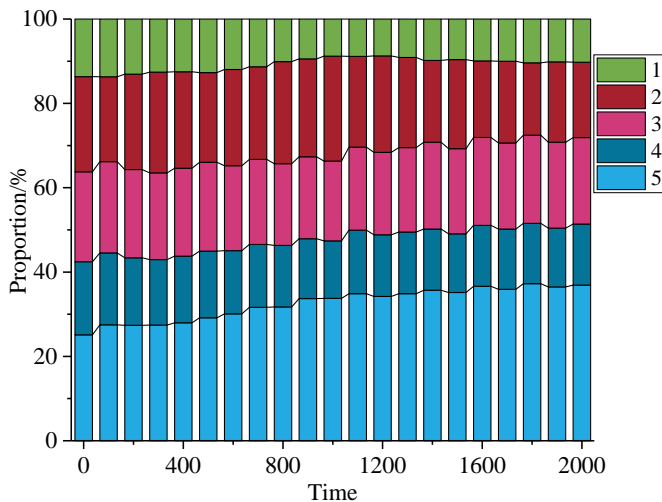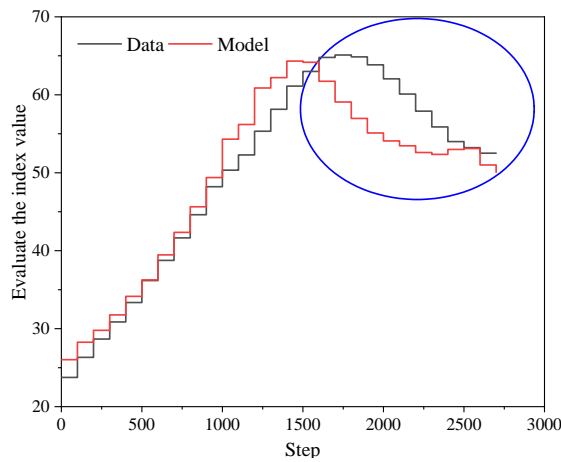
Fig. 12. Model validation and prediction diagrams.

## VI. CONCLUSION

*1)* The real number variation method shows obvious 01 bidirectional variations with the increased iteration number. The corresponding binary variation method displays the linear change of two sections with different slopes. It is worth explaining that the increasing of samples can promote the improvement of test accuracy.

*2)* The neuron data under the genetic algorithm has typical linear variation characteristics, while the neuron spacing curve under the influence of initial domain radius and time constant presents distinct nonlinear characteristics. This indicates that the original model cannot describe the changes in the test data well, and further optimization and analysis of the model are needed.

*3)* As the number of iterations increases, the influence curves of the genetic algorithm under four different parameters are shown as follows: Parameter A increases slowly at first and then presents a relatively gentle nonlinear change; Parameter U decreases gradually and then rapidly; Parameter m stays at about 70 on the whole. The parameter I shows typical linear characteristics.

*4)* The accuracy of the corresponding genetic optimization algorithm can be obtained by calculating the corresponding accuracy index and the accurate total number, and the relevant change curve can be drawn as follows: The curve of accuracy R first showed a significant downward trend and then linearly increased. And the increase in iteration and calculation times can improve the accuracy of calculation results.

However, this article also has certain limitations. The CNN model based on genetic algorithm requires a large amount of computing resources, which will consume significant time during training and usage. Meanwhile, for small image datasets, this may not achieve good performance. This may be difficult to solve specific problems such as accurate positioning of objects in images. The scale and quality of the corpus on which an automatic scoring system relies directly affect the accuracy of the system. Therefore, future research should focus on establishing more complete, standardized, and representative corpora. Expand coverage and classification fineness, improve

the universality and accuracy of the system. Natural language processing can only process textual information, while English automatic scoring includes not only text but also information such as voice and images. Therefore, future research should focus on integrating multimodal information to achieve multimodal automatic scoring systems, improving the comprehensiveness and accuracy of scoring.

### REFERENCES

[1] D. Peng, G. Tan, K. Fang, L. Chen, P. K. Agyeman, and Y. Zhang, "Multiobjective optimization of an off-road vehicle suspension parameter through a genetic algorithm based on the particle swarm optimization," Math Probl Eng, vol. 2021, pp. 1–14, 2021.

[2] M. Barthwal, A. Dhar, and S. Powar, "The techno-economic and environmental analysis of genetic algorithm (GA) optimized cold thermal energy storage (CTES) for air-conditioning applications," Appl Energy, vol. 283, p. 116253, 2021.

[3] M. Mangera, J. O. Pedro, and A. Panday, "Direct adaptive neural network-based sliding mode control of a high-speed, ultratall building elevator using genetic algorithm," SN Appl Sci, vol. 4, no. 4, p. 100, 2022.

[4] K. Cai, X. Li, and L. H. Zhi, "Extracting time-varying mean component of non-stationary winds utilizing Vondrak filter and genetic algorithm: A wind engineering perspective," International Journal of Structural Stability and Dynamics, vol. 21, no. 11, p. 2150155, 2021.

[5] N. Ben Latifa and T. Aguili, "Optimization of coupled periodic antenna using genetic algorithm with floquet modal analysis and mom-gec," Open Journal of Antennas and Propagation, vol. 10, no. 1, pp. 1–15, 2022.

[6] S. Li et al., "Development of a reduced chemical reaction mechanism for n-pentanol based on combined reduction methods and genetic algorithm," ACS Omega, vol. 6, no. 9, pp. 6448–6459, 2021.

[7] S. Das, T. Samanta, and A. K. Datta, "Improving black tea quality through optimization of withering conditions using artificial neural network and genetic algorithm," J Food Process Preserv, vol. 45, no. 3, p. e15273, 2021.

[8] J. Wang, R. Wang, M. Yang, and D. Xu, "Understanding zinc-doped hydroxyapatite structures using first-principles calculations and convolutional neural network algorithm," J Mater Chem B, vol. 10, no. 8, pp. 1281–1290, 2022.

[9] Y. Zhou, H. Chen, Y. Li, S. Wang, L. Cheng, and J. Li, "3D multi-view tumor detection in automated whole breast ultrasound using deep convolutional neural network," Expert Syst Appl, vol. 168, p. 114410, 2021.

[10] M. AbiarKashani, Y. Alizadeh Vaghasloo, and M. AghaMirsalim, "Optimal design of high-pressure fuel pipe based on vibration response and strength using multi-objective genetic algorithm," Structural and Multidisciplinary Optimization, vol. 64, pp. 935–956, 2021.

[11] D. Żelasko, W. Książek, and P. Pławiak, "Transmission quality classification with use of fusion of neural network and genetic algorithm in Pay&Require multi-agent managed network," Sensors, vol. 21, no. 12, p. 4090, 2021.

[12] S. Güler and S. Yenikaya, "Analysis of shielding effectiveness by optimizing aperture dimensions of arectangular enclosure with genetic algorithm," Turkish Journal of Electrical Engineering and Computer Sciences, vol. 29, no. 2, pp. 1015–1028, 2021.

[13] X. Lin et al., "Optimized neural network based on genetic algorithm to construct hand-foot-and-mouth disease prediction and early-warning model," Int J Environ Res Public Health, vol. 18, no. 6, p. 2959, 2021.

[14] G. Long, Y. Wang, and T. C. Lim, "Optimal parametric design of delayless subband active noise control system based on genetic algorithm optimization," Journal of Vibration and Control, vol. 28, no. 15–16, pp. 1950–1961, 2022.

[15] S. Y. Martowibowo and B. Kemala Damanik, "Optimization of material removal rate and surface roughness of AISI 316L under dry turning process using genetic algorithm," Manufacturing Technology, vol. 21, no. 3, pp. 373–380, 2021.

[16] X. Han, D. Liang, and H. Wang, "An optimization scheduling method of electric vehicle virtual energy storage to track planned output based on multiobjective optimization," Int J Energy Res, vol. 44, no. 11, pp. 8492–8512, 2020.

[17] Z. Ran, W. Ma, C. Liu, and J. Li, "Multi-objective optimization of the cascade parameters of a torque converter based on CFD and a genetic algorithm," Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering, vol. 235, no. 8, pp. 2311–2323, 2021.

T. Zhu, L. Wang, X. Na, T. Wu, W. Hu, and R. Jiang, "Research on on Novel Fuzzy Control Strategy of Hybrid Electric Vehicles Based on Feature Selection Genetic Algorithm.," Sensors & Materials, vol. 33, 2021.

[19] K. Kassoul, N. Cheikhrouhou, and N. Zufferey, "Buffer allocation design for unreliable production lines using genetic algorithm and finite perturbation analysis," Int J Prod Res, vol. 60, no. 10, pp. 3001–3017, 2022.

[20] T. Zhu, Y. Qin, Y. Xiang, B. Hu, Q. Chen, and W. Peng, "Distantly supervised biomedical relation extraction using piecewise attentive convolutional neural network and reinforcement learning," Journal of the American Medical Informatics Association, vol. 28, no. 12, pp. 2571–2581, 2021.

[21] Y. Ding et al., "AP-CNN: Weakly supervised attention pyramid convolutional neural network for fine-grained visual classification," IEEE Transactions on Image Processing, vol. 30, pp. 2826–2836, 2021.

[22] P. Khosravian, S. Emadi, G. Mirjalily, and B. Zamani, "QoS-aware service composition based on context-free grammar and skyline in service function chaining using genetic algorithm," PeerJ Comput Sci, vol. 7, p. e603, 2021.

# Construction of Sports Culture Recommendation Model Combining Big Data Technology and Video Semantic Comprehension

Bin Xie[1], Fuye Zhang[2]

Department of Physical Education, Henan Institute of Economics and Trade, Zhengzhou 450046, Henan, China[1]
Internet of Things College, Henan Institute of Economics and Trade, Zhengzhou 450046, Henan, China[2]

*Abstract*—Information blast makes it harder for clients to channel the substance they are keen on. This study aims to combine big data and video semantic comprehension technology to realize the recommendation of sports culture videos by exploring the semantics of video and taking advantage of multi-source heterogeneous information. The semantic structure of unstructured video data is defined first, and on this basis, Converse3D (C3D) - Connectionist Temporal Asifationon (CTC) is employed to complete the extraction of sub-action semantics and the integration of behaviour semantic sequences. In adjustment to break the botheration of low accurateness of the model for the semantic abstraction of unlabeled videos, this study proposes an unsupervised semantic abstraction adjustment based on Converse3D(C3D)-RAE, which completes the compression and affiliation of the semantic sequences and verifies the accurateness of both two models through experiments. In order to solve the problem of insufficient accuracy of video recommendation algorithms based on single video semantic similarity and topic similarity, this study comprehensively considers video semantic similarity and video topic similarity and proposes a multi-modal video recommendation algorithm. The experimental results show that the accuracy of the COMSIM-based algorithm is 7.8% higher than that of Video+ CNN + K-NearestNeighbor (KNN) and 15.9% higher than that of CLIP + CNN +Ncut+LDA.

*Keywords*—*Big data; video semantic comprehension; sports culture; semantic sequences; convolutional neural networks (CNN)*

## I. INTRODUCTION

With the rapid advancement of information technology in recent years, the Internet has brought convenience to people's lives, providing them with a large amount of data and information resources, greatly satisfying people's demand for network information, and moving the Internet industry into the big data era [1], [2]. However, excessive information from multiple sources has also become an obstacle for people to enjoy convenience. Specifically, information in the new era is no longer delivered to users by websites or media in one direction, but more often than not, users and media have formed an effective two-way transmission, which has significantly expanded the existing data stock [3], [4]. In addition, the continuous sinking of the user market has led to the exponential expansion of the user community and the exponential growth of data [5]. However, instead of enjoying convenient services, the huge amount of data and information has plunged people into the vast data mud, a trap known as

"information overload". For Internet users, it is undoubtedly difficult to find the data knowledge they need in the exponentially growing data information, and users usually need to spend a lot of time and effort to find this information, which leads to a very poor user experience [6], [7]. For service providers, it is difficult to fully explore users' interests and preferences due to the large amount and complex types of log information generated by users, so they cannot accurately determine the content of users' needs, which greatly reduces the service quality and may push inaccurate information to users, which destroys users' trust in the system and leads to user churn [8], [9]. Faced with the information overload network environment and multiple sources of heterogeneous data types, how to make users less frustrated when searching for information, how to deepen users' trust in service providers, and how to enable service providers to maximize the benefits of efficiency are hot issues that need to be solved in the current data mining field.

At present, there are two main ways to solve this problem: information retrieval technology and information filtering method [10], [11]. The content presented by search engines for different users is often the same, which cannot meet the personalized needs of each user. The personalized recommendation technology based on information filtering does not require users to give their specific needs [12]. It can mine users' interests and preferences through users' historical behaviour logs and browsing habits to generate relevant recommendations [13], [14]. In today's big data era, personalized recommendation technology can greatly improve the efficiency of processing problems and meet the personalized needs of users. This technology has been successfully applied to many fields and has become a research hotspot in the computer application field.

Digital video data contains abundant spatial and temporal information, but it is difficult to describe the video content because of its huge amount of data and the semantic gap between low-level features and high-level semantics [15], [16]. With the rapid development of deep learning, especially the development of cross-modal learning, people's understanding of video semantics has reached a new level. Therefore, based on the video semantic understanding model, this paper proposes a sports culture video recommendation method that integrates video semantics and video topic text similarity.

This article analyzes the construction technology of sports culture models that combine video semantics. The accuracy of the model was verified through data recommendation of diverse and heterogeneous information. The innovation points include:

*1)* By exploring the semantics of videos and utilizing heterogeneous information from multiple sources, sports culture videos can be recommended.

*2)* This article uses C3D-CTC to extract sub action semantics and integrate behavioral semantic sequences. In order to overcome the problem of low accuracy in unlabeled video semantic abstract models.

*3)* This article addresses the issue of insufficient accuracy in video recommendation algorithms based on single video semantic similarity and topic similarity.

Section I analyzes the background of uncertainty when users search for information in the face of information overload in the network environment and the multi-source nature of heterogeneous data types. How to deepen users' trust in service providers has become a current issue worth studying. Section II analyzes video recommendation algorithms as a popular component of recommendation systems. Considering the issue that topic modeling techniques cannot cluster short texts that ignore semantic relationships between words. Section III recommends methods for sports culture videos that consider multiple modes and analyzed the semantic extraction of sports videos in C3D. Section IV conducted validation analysis on the dataset used, including the UCF-12 dataset and the sports video dataset captured from the video website Vine.com. Section V summarizes the entire text. This study proposes an unsupervised semantic abstraction adjustment method based on C3D-RAE, which completes the compression and membership of semantic sequences, and verifies the accuracy of the two models through experiments.

## II. Related Work

Video recommendation algorithms, as an important component of recommendation systems, have always been a hot research direction. Considering the disadvantage of topic modeling technology not being able to cluster short texts that ignore semantic relationships between words, M S Tajbakhsh et al. [17] proposed a topic modeling method for semantic relationships between words in Twitter social network tweets. Yaduv U et al. [18] proposed a recommendation system method based on linked open data and social network features. This method solves the problem of pure new user cold start by constructing user profiles based on collaborative features of linked public data and features of social networks. Nikolakopoulos et al. [19] proposed the EIGENREC recommendation model based on the existing PureSVD algorithm, which comprehensively utilizes multiple recommendation strategies. The created model can modify recommendation results in real-time based on the popularity of the project. Salah et al. proposed a weighted clustering method to address the issue of data sparsity in dynamic incremental collaborative filtering. The experimental results showed that the constructed model has fast computational speed and low computational cost [20]; Hewitt et al. classified eight types of

emotions and proposed three improved convolutional neural networks to implement a music recommendation interface based on predicting user influence [21]. In order to solve the cold start problem caused by the lack of correlation score when adding new videos, Li Y et al. [22] proposed directly calculating video correlation from the content. And use deep convolutional neural networks to process video information, thereby constructing a video correlation table. Li X et al. [23] proposed a multi-directional pyramid common attention module for learning the attention values of two modalities in different dimensional spaces. Fan C et al. [24] viewed the semantic information of videos as a series of ordered events that occur in sequence as a whole and are continuously read and written to memory. The input sequence can be understood from a global perspective to prevent local capture due to information interference.

In summary, the current research model cannot perform sparsity analysis on dynamic incremental collaborative data. This indicates that there are certain shortcomings in the video correlation of emotional users. For a long time, users have been plagued by low accuracy of unlabeled video semantic abstract models. On this basis, this article optimizes multi-source heterogeneous information. Using C3D-CTC to extract sub action semantics and integrate behavioral semantic sequences. It breaks the problem of low accuracy in unlabeled video semantic abstract models.

## III. Sports Culture Video Recommendation Method Considering Multi-Modality

### A. Semantic Extraction for Sports Videos based on C3D

*1) Video behaviour semantic extraction based on supervised learning*: Since video data is unstructured data, in order to analyze and process video more accurately, video data must be structured, which is the basis of video feature extraction and semantic extraction. Video is a continuous frame sequence with no obvious segmentation point. It isn't easy to extract the semantics of the entire video directly. Therefore, it is necessary to divide the video into multiple segments and extract the semantics of the segments respectively. Video can be divided into the following levels according to its physical level: video, scene sequence, shot sequence and frame sequence, as shown in Fig. 1.
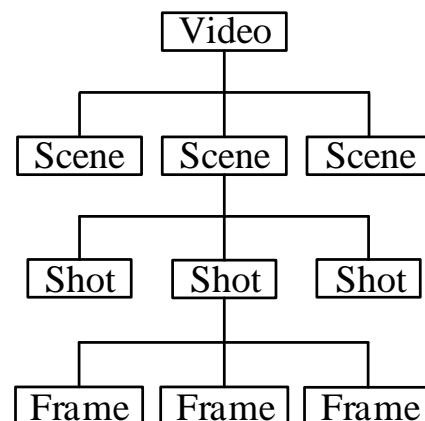


Fig. 1. Hierarchical structure of video.

Scene: A group of shots expressing the same theme. These shots record an event at the same time and place from different angles in space. Together, they describe the semantic concepts related to this event. For example, the scene of "air relay" can be composed of multiple shots such as "player passing", "another player is catching the ball in the air", "player shooting", or "player dunking", "ball in", etc. Shots: a recording process of a camera. Shots are the logical component unit of video and are also the smallest unit that can be used in indexing video. As the physical unit of video, a frame is defined as the frame is the smallest unit of video image - a single picture.

According to the physical hierarchy of video, this study defines the semantic structure of video as shown in Fig. 2.
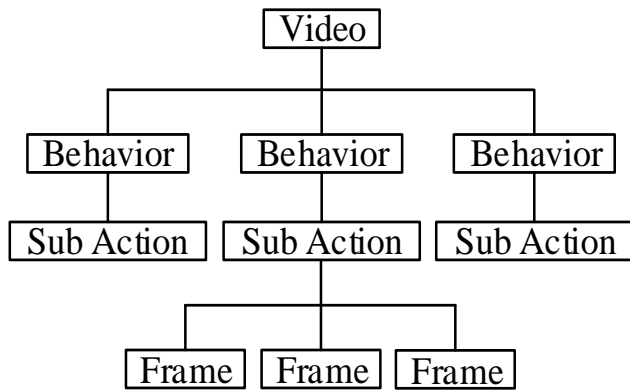


Fig. 2. Semantic structure of video.

Convolutional Neural Networks (CNN) have been extensively used in computer vision-related research in recent years, whose structure mainly includes a convolution layer, pooling layer and full connection layer. In image processing, CNN generally adopts the "planar convolution" with the dimension of convolution kernel of 2. However, when analyzing video, 2D convolution has a poor ability to capture timing information, leading to the loss of video timing information.

Therefore, 3D Convolutional Neural Network (C3D) with a convolution kernel dimension of three is adopted in this study, which can capture features in both temporal and spatial dimensions. The concrete implementation of 3D convolution operation is as follows: a three dimensions frame cube is obtained by stacking several consecutive frames, and the cube is convolved with the 3D convolution kernel, as shown in Fig. 3, where the connection of the same colour represents the shared weight, that is, there are weight values of three dimensions. Through such a convolution operation, the feature map obtained by convolution is connected with several consecutive frames of the previous layer to capture the timing information. D. Tran et al. [25] found that the same convolution kernel structure of 3*3*3 has the best accuracy on C3D. Therefore, the same convolution kernel of 3 * 3 * 3 is employed in this study.
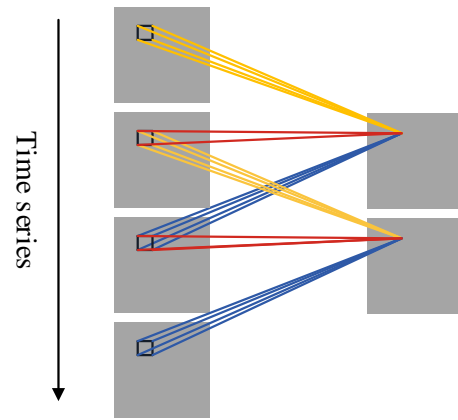


Fig. 3. 3D convolution.

Due to the large amount of redundant information between video frames and sub-actions, as well as the repetition of video frames in the time dimension, the extraction of video semantics will be affected. Therefore, this study puts to use the connectionist temporal classification (CTC) to solve the above problems. CTC algorithm was first applied in the acoustic training model, which is a complete end-to-end training without strict alignment of data in advance. For example, to understand intra coding, most areas of the image have the same color. False i will encode the red area, assuming that the colors in the frame remain consistent in the vertical direction. This means that the color of the unknown pixel is the same as that of adjacent pixels. Although this prior prediction technique (intra frame prediction) is used, the actual value is subtracted to calculate the residual. The residual matrix obtained in this way is easier to compress than the original data [26]. Yang improved the recognition algorithm by analyzing graph regularization and constructing a model, and compared and analyzed feature extraction methods. Meanwhile, the experiment aims to investigate the improvement of the improved recognition algorithm on English semantic translation after feature extraction [27]. Traditional content-based video retrieval algorithms typically only utilize the underlying features of video images, resulting in insufficient content description and unsatisfactory retrieval results. Guo studied how to combine the underlying features of videos with semantic features, improved the existing indexing structure, and designed an efficient sports video retrieval algorithm [28].

C3D is applied to model the sub-action features first, and different kinds of probability distributions of each sub-action are obtained. $x$ represents the sub-action sequence, and $y$ represents the output sequence of C3D.

The output of the C3N model is the probability of the category corresponding to each sub-action, which is a vector of N+1-dimensional probabilities, representing the different probabilities of N+ 1 category, N represents the number of sub-action categories, and 1 represents blank. We employ $N_w$ to represent the convolutional neural network, and then the network output can be expressed as:

$$y = N_w(x) \quad (1)$$

For any sub-action input sequence of length $T$, whose corresponding label sequence is $z$, we can obtain that the

occurrence probability of label sequence $z$ is the product of label probabilities at each moment.

$$P(\pi|x) = \prod_{t=1}^{T} P(\pi_t|x) \quad (2)$$

Where $\pi$ denotes the decoding path and $\pi_t$ represents the $t$-th sub-action label in the decoding path.

The probability of decoding path $\pi$ can be calculated from the output of the C3D model as follows:

$$P(\pi|x) = \prod_{t=1}^{T} y_{\pi_t}^t \quad (3)$$

where, $y_{\pi_t}^t$ denotes the probability that the $t$-th sub-action label is $\pi_t$.

Define a many-to-one mapping B to remove all blank symbols and merge duplicate labels, transforming the decoding path $\pi$ into label $l$. For example, (-,A,-,-,E,-) and (-,A,-,E,-,-) are both mapped to label (A,E). B$^{-1}$ represents the inverse process of mapping B, which is a one-to-many mapping, that is, mapping label (A, E) into a sequence of labels with duplicate labels and blank symbols for all possible decoding paths so that the final decoding path $\pi$ is the sum of the probability of each sequence with the probability of the label sequence given the input sequence $x$.

$$P(l|x) = \prod_{t=1}^{T} P(\pi|x), \pi \in B^{-1}(l) \quad (4)$$

Given an input sequence $x$ and the corresponding label $l$, the loss function of the C3D-CTC model adopts the maximum likelihood error, that is, to minimize the negative logarithm of the probability:

$$\text{C3D-CTC}(x) = -\log P(l|x) \quad (5)$$

In Eq. (4), the calculation of the objective function requires an exhaustive enumeration of all decoding paths, which is very difficult. In fact, only a small part of all paths are effective. Therefore, this study adopts the Forward-Backward Algorithm (FBA), a kind of dynamic programming algorithm, to calculate the objective function of the model.

For a given label $l$ of length T, in order to find all paths $\pi$ satisfying $l = B(\pi)$, we need to construct an extended label $l'$, whose length is 2T+1 by adding a blank at the beginning, end and middle of each character. For example, the sequence (A, E), whose extension label L 'is (-,A,-,E,-). The legal decoding path must meet the following conditions: (1) The path conversion can only be right or down; (2) There must be a

For the part without connection in the upper right corner, it represents the node that cannot be reached by the legal decoding path, so we can add restrictions and set the probability of these paths to 0.

$$\begin{cases} \alpha_t(s) = 0, \forall s < 1 \\ \alpha_t(s) = 0, \forall s < |l'| - 2(T - t) - 1 \end{cases} \quad (9)$$

Therefore, the loss function of the C3D-CTC model can be expressed as follows:

$$-\ln(P(l|x)) = -[\ln(\alpha_T(2T+1) + \alpha_T(2T))] \quad (10)$$

blank between the same characters; (3) Only blank symbols can be skipped; (4) The path must start with the first two symbols; (5) The path must end with the last two symbols. The conversion process of all decoding paths of label $l$ is shown in Fig. 4.
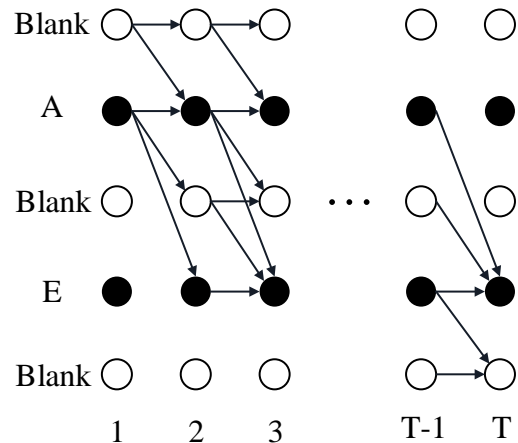


Fig. 4. All decoding paths of the label 'AE'.

To calculate the sum of the probabilities of all the above decoding paths, define the forward probability $\alpha_t(s)$ to denote the sum of the forward probabilities of all paths at the $t$-th input with $s$ as the endpoint:

$$\alpha_t(s) = \sum_{B(\pi_{1:t})=l_{1:s}} \prod_{t'=1}^{t} y_{\pi_{t'}}^{t'} \quad (6)$$

Where $s$ denotes the number of rows, the initial state of the forward probability $\alpha_t(s)$ can be calculated as follows:

$$\begin{cases} \alpha_1(1) = y_{blank}^1 \\ \alpha_1(2) = y_{l_1}^1 \\ \alpha_1(s) = 0, \forall s > 2 \end{cases} \quad (7)$$

The decoding path shows that: (1) there are only two possibilities from blank, either blank or $l_i$, i.e., the $i$-th element of label $l$; (2) there are threecases from $l_i$, that is, $l_i$, blank and $l_i$+1, with 3 possible output cases; (3) the input case of the blank is two and the input case of $l_i$ is 3. We can obtain $\alpha_t(s)$ with the following iterative formula.

$$\alpha_t(s) = \begin{cases} (\alpha_{t-1}(s) + \alpha_{t-1}(s-1))y_{l_s}^t, & \text{if } l_s = blank \text{ or } l_{s-2} = l_s \\ (\alpha_{t-1}(s) + \alpha_{t-1}(s-1) + \alpha_{t-2}(s-1))y_{l_s}^t, & \text{otherwise} \end{cases} \quad (8)$$

The video behaviour semantic extraction model based on C3D-CTC is shown in Fig. 5.

*2) Video latent semantic extraction Based on unsupervised learning*: For some videos with blurred boundaries between actions, the C3D-CTC model is difficult to get accurate labels by action decomposition, and its scalability for new types of videos is poor. In order to solve the above problems, this study proposes a Recursive Auto-Encoder (RAE) based video latent semantic extraction method.
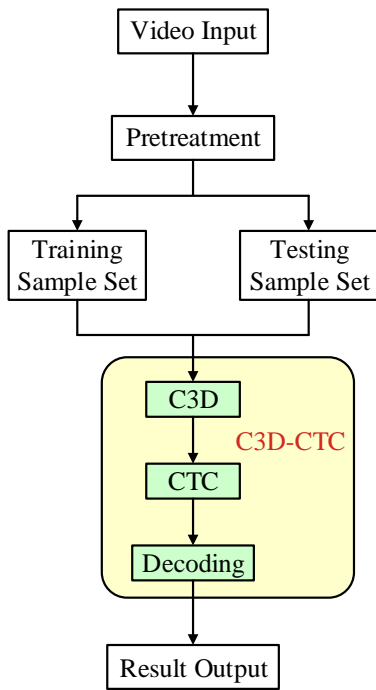
Fig. 5. C3D-CTC model.

RAE is an auto-encoder that searches for variable-length input structures, which is put to use in both NLP and computer vision. When the input is a sequence of word vectors, RAE uses neural networks to sense the score of all two adjacent word vectors. By measuring the probability of synthesizing a word for each pair of word vectors, the one with the largest probability is selected as the representative of the two-word vectors, the vector of the two words is removed from the sequence, and the synthesized vector is inserted into the position of the previous two words in the sequence. This is done recursively until the entire input statement is mapped to a vector at the root of the binary tree.

The input word vector sequence is $(x_1, x_2, x_3, x_4, x_5)$, then the encoding process of word vector pair $(x_1, x_2)$ transforming to parent node $y_1$ is defined as:

$$y_1 = f(W^{(1)}[x_1, x_2] + b^{(1)}) \quad (11)$$

where, $W^{(1)}$ represents the $n*n$ matrix parameters and $b^{(1)}$ is a bias term.

The decoding process of the parent node $y_1$ reconstructing $x_1$ and $x_2$ can be presented as follows:

$$[x_1', x_2'] = W^{(2)} y_1 + b^{(2)} \quad (12)$$

The reconfiguration error of the auto-encoder is as follows:

$$E_{rec}([x_1, x_2]) = \frac{1}{2} \| [x_1, x_2] - [x_1', x_2'] \|^2 \quad (13)$$

Define A($x$) as all adjacent node pairs of the input sequence $x$, and define T($y$) as the case where the binary child node is transformed into the parent node. We define the objective function of the recursive auto-encoder as:

$$VE(x) = \underset{y \in A(x)}{argmin} \sum_{s \in T(y)} E_{rec}([x_1, x_2]_s) \quad (14)$$

When generating weights, in order to avoid weight skew, the reconstruction errors generated each time should be normalized.

$$E_{rec} = \frac{n_1}{n_1 + n_2} \| x_1 - x_1' \|^2$$

$$+ \frac{n_2}{n_1 + n_2} \| x_2 - x_2' \|^2 \quad (15)$$

The binary tree recursive structure of the RAE is shown in Fig. 6.
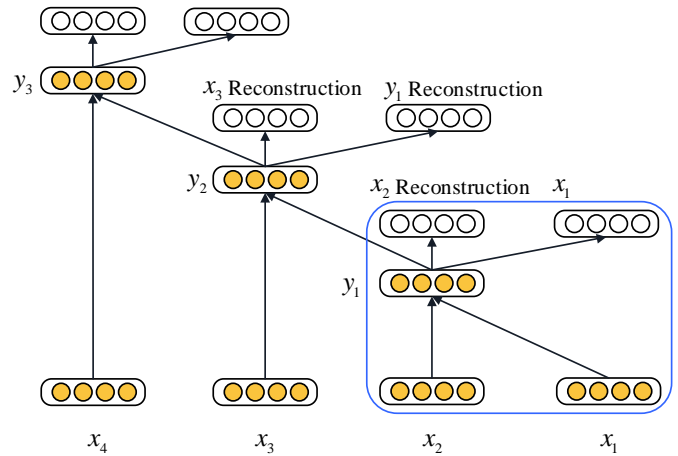


Fig. 6. Binary tree recursive structure of the RAE.

The input feature sequence is paired by $(x_0, x_1),(x_1, x_2),...,$ $(x_{n-1}, x_n)$, calculate the reconstruction error of all the paired nodes, select the pair with the smallest error value to generate the parent node into the input sequence, then remove the pair from the input sequence, and repeat the above steps until only one node remains in the input sequence. At this point, this node is the potential semantic feature of the input sequence.

The video latent semantic extraction model encodes the output of the fully-connected layer of 3D-CNN by unsupervised RAE to obtain video latent semantic features, and its specific model structure is shown in Fig. 7.
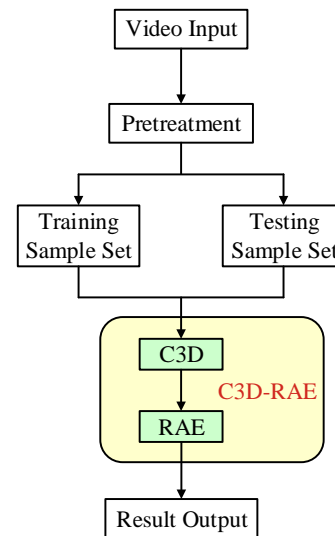


Fig. 7. C3D-RAE model.

## B. Sports Culture Recommendation Model

*1) Video recommendation based on text topic similarity*: This research adopts the Latent Dirichlet Allocation (LDA) topic model to accomplish the topic extraction of video description information. The goal of the LDA topic model is to find the distribution of topics in each document and the distribution of words in each topic. How to calculate similarity specifically? This article calculates the similarity between two videos based on the metadata information of the videos. Simultaneously, using similarity ranking from high to low, obtain the most similar topN of a certain video as an association or similarity recommendation. Although both long and short videos use the same algorithm system, the front-end product form varies due to different video types. Due to the short duration of a single short video, it usually takes a few minutes to play. Therefore, the recommended method for associating short videos is to use information flow to play the original video. The videos associated with it will be played as information streams, which will greatly improve the overall user experience. When training the LDA topic model, the number of topics $K$ needs to be given first, and all distributions are expanded based on $K$ topics. The specific LDA topic model algorithm is shown in Fig. 8.
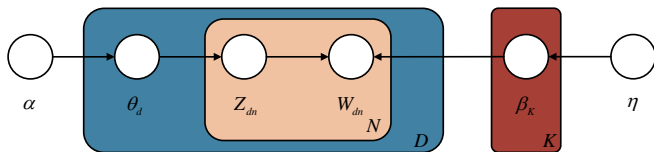


Fig. 8. LDA algorithm.

LDA assumes that the prior distribution of document topics is Dirichlet distribution; that is, for each document $d$, its topic distribution $\theta_d$ is:

$$\theta_d = Dirichlet(\alpha) \qquad (16)$$

Where $\alpha$ is a hyperparameter in the distribution and is a $k$-dimensional vector. LDA has a premise that the prior distribution of the words in the topic satisfies the Dirichlet distribution; that is, for each topic $k$, the distribution $\beta_k$ of its words is:

$$\theta_k = Dirichlet(\eta) \qquad (17)$$

Wherein, $\eta$ is a hyperparameter in the distribution and is a $v$-dimensional vector. v here stands for the number of words in the total vocabulary. For the $n$-th word in each document $d$, we can obtain the distribution of its topic number $z_{dn}$ from the topic distribution $\theta_d$ as follows:

$$z_{dn} = multi(\theta_d) \qquad (18)$$

And for that topic number zdn, the probability distribution of the word wdn is obtained as:

$$w_{dn} = multi(\beta_{z_{dn}}) \qquad (19)$$

In the LDA model, there are $M$ Dirichlet distributions of document topics, and the corresponding data have $M$ multinomial distributions of topic numbers, so $(\alpha \rightarrow \theta_d \rightarrow z_d)$ forms Dirichlet-multi conjugate. The posterior distribution of document topics based on Dirichlet distribution can be obtained by the Bayesian inference method. Defined in the $d$-th document, the total number of the $k$-th subject word is $n_d^{(K)}$, then the corresponding multinomial distribution can be expressed as follows:

$$n_d = (n_d^{(1)}, n_d^{(2)}, \ldots, n_d^{(K)}) \qquad (20)$$

By using the Dirichlet-multi conjugate, the posterior distribution of $\beta_k$ is obtained as follows:

$$Dirichlet(\beta_k | \eta + n_k) \qquad (21)$$

The specific process of the recommendation algorithm based on LDA topic model is as follows: (1) select the initial topic number $K$ value, train the LDA model, and calculate the similarity between each topic in the trained LDA model; (2) increase or decrease the value of $K$ according to whether the topic similarity decreases, retrain the LDA model, and calculate the similarity between the topics again; (3) repeat the second step until the optimal $K$ value is obtained when the similarity between topic is minimized.

*2) Sports culture video recommendation considering multi-modal characteristics*: In order to make full use of the multi-source heterogeneous information of videos, this study proposes a video recommendation algorithm considering multi-modal characteristics (RAMM) to improve the accuracy of video recommendations. The RAMM recommendation algorithm is a fusion of three different algorithms which are applied to different problems. When the video belongs to a labelled video, the recommendation based on C3D-CTC is employed. When the video belongs to an unlabelled video, the recommendation based on C3D-RAE is employed, and when the video has description information, the recommendation based on LDA is employed. The specific structure is shown in Fig. 9.
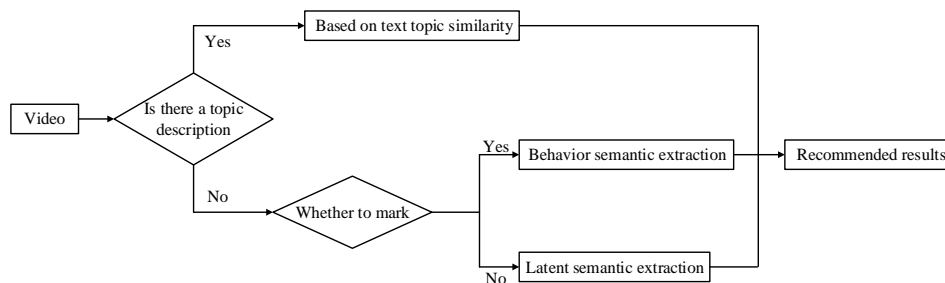


Fig. 9. Recommendation considering multi-modal characteristics.

This study constructs a comprehensive method for calculating video similarity considering the multi-modal characteristics ComSim.

$$Comsim(x, y) = \beta \cdot SimSemantic(x, y)$$

$$+(1 - \beta) \cdot SimTopic(x, y) \qquad (22)$$

Where $\beta$ is a hyperparameter, *SimSemantic* represents semantic similarity, and *SimTopic* represents text similarity. The larger $\beta$ is, the higher the model's bias towards semantics and, conversely, the higher the bias towards topic information.

## IV. EMPIRICAL ANALYSIS

The datasets employed in this study contain the UCF-12 dataset and sports video set crawled from the video website Vine.co. The UCF-12 dataset is a specific set of 12 categories of videos excerpted from the UCF-101 video set, mainly including basketball shooting, basketball dunking, bowling, high jump, soccer free throw, cycling, skiing, volleyball dunking, table tennis hitting, pole vaulting, fencing, and rope skipping. Each of these categories consists of 25 groups, each group containing four to seven videos, with the shortest video lasting three seconds and the longest video lasting eight seconds, for a total of 1760 videos. The videos in this dataset have better stability and high similarity of actions in each category, with fewer interfering factors unrelated to the videos. The Vine dataset is crawled from the video website Vine.co sports category videos, consisting of a total of 2400 videos, and because this video set is directly crawled from the website and has not been processed manually, its content similarity is lower than the UCF-12 dataset. The videos contain some interfering factors that are not related to the video content.

Before training the model, the video data needs to be reprocessed. First, all test videos are converted into image sets at 20 frames per second, and for videos whose number of images does not meet a multiple of eight, the last frame is copied and added at the end. Then, to prevent spatial jitter, we scale the images to a uniform size of 112*112. We divide the dataset into a training dataset and a test dataset in a ratio of 9:1 for completing model training and model testing. The topic text similarity and potential semantic similarity of different videos are calculated by the cosine theorem, and the behavioural semantic similarity (*SimBs*) of different videos is defined as follows:

$$SimBs(m, n) = \begin{cases} ecp(m, n), |m| = |n| \\ ncp(m, n), |m| \neq |n| \end{cases} \qquad (23)$$

When the lengths of semantic sequences *m* and *n* are equal, the value is the ratio of the total number of semantic equivalents to the length of *m*. When the lengths of semantic sequences *m* and *n* are unequal, the value is the ratio of the length of the common maximum continuous subsequence of *m* and *n* to min (*m*, *n*).

### A. Training Parameter Selection

Parameter tuning is crucial to the final performance of the model, and appropriate parameter selection can effectively improve the generalization ability of the model. In order to measure the impact of various parameter changes, this study adopts the control variable method to select the learning rate and batch size of the model. The results are shown in Fig. 10 and Fig. 11.
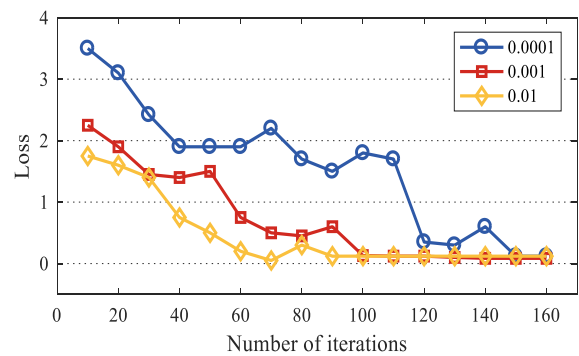


Fig. 10. The impact of learning rate on the Loss function.
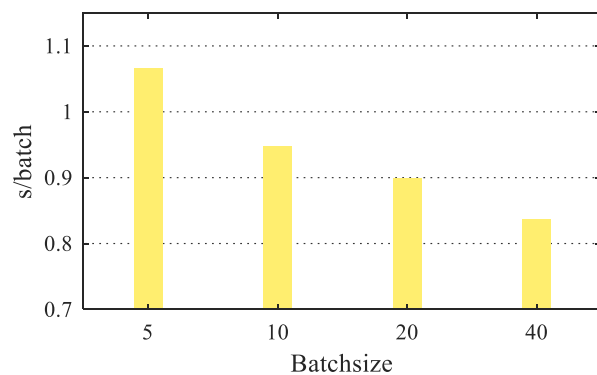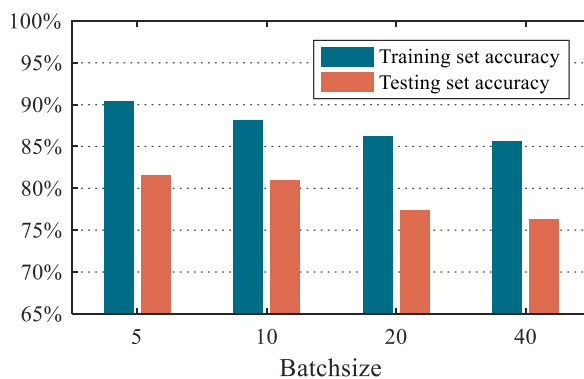


Fig. 11. The impact of batch size on model.

As it can be seen from Fig. 11, when the learning rate is 0.01 and 0.001, the model loss decreases rapidly for a period with the increase of training times and then gradually becomes stable at last. For the learning rate of 0.0001, when the number of training iterations reaches 160, the model is still in a state of oscillation and cannot converge, and the loss value is higher than the other two learning rates. When the learning rate is 0.01, the model reaches the convergence point at the fastest speed, and the loss value is lower than that of 0.0001 but higher than that of 0.001. That is, if the learning rate is too low, the trained model will be more reliable, but it will take longer for the model to reach the convergence point, and it still cannot converge on the basis of the same training time. If the learning rate is too high, the model will reach the convergence point very early. The learning rate is chosen as 0.001 for the model through the experiment of learning rate in this section.

It can be seen from Fig 12 that under the same model and the same data set, different values of Batchsize have an impact on the test accuracy of the model. It can be observed that the larger the value of Batchsize is, the less iteration will be required to process the same amount of data, and the less convergence time will be lost, but the accuracy will also be reduced. Through selection, the batch size value selected in this study is 10.

### B. Impact of Different Algorithms on the Accuracy of Video Semantic Comprehension

Different algorithms lead to different accuracy of video semantic comprehension of the model, and this study compares the accuracy of the model behavioural semantic comprehension model and latent semantic comprehension model when adopting different algorithms, and the results are shown in Fig. 12 and Fig. 13 respectively.
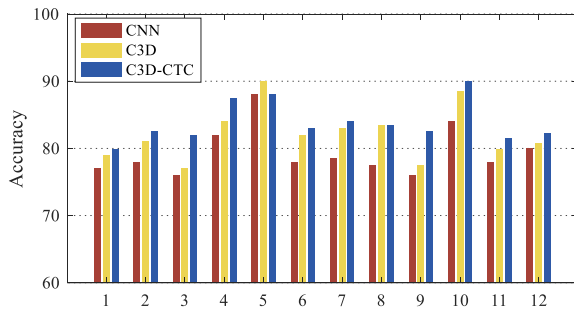


Fig. 12. Semantic comprehension accuracy of different algorithms.
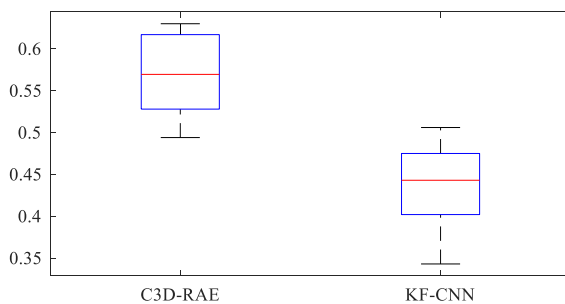


Fig. 13. Cosine similarity of different algorithms.

In Fig. 13, the horizontal coordinates indicate basketball shooting, basketball dunking, bowling, high jump, riding, soccer free throw, skiing, volleyball dunking, table tennis hitting, pole vaulting, fencing, and rope skipping, respectively. It can be seen that the accuracy of the C3D-CTC model is higher than the other algorithms except for the sport of riding, which is due to the fact that the result sequence of riding has a boosting behaviour, which affects the accuracy of C3D-CTC. By analyzing the test results, we found that the categories with no significant differentiation between sub movements achieved higher accuracy on the models in this section than those with significant differentiation between sub movements.

As it can be seen from Fig. 14, the box plot should start from the statistical points, and it can be seen that the C3D-RAE clustering accuracy used in this article is 0.57, while the statistical position of KF-CNN is 0.35. Therefore, C3D-RAE has a clustering accuracy of 22% higher than KF-CNN. Therefore, under unsupervised conditions, C3D-RAE has higher clustering accuracy than keyframe image semantic extraction algorithms and measured through average cosine similarity. Compared with the KF-CNN algorithm using video key frame image semantics, the C3D-RAE model has a larger average similarity between each data type and the center point in the clustering results, and the distribution of the clustering results is more uniform.

### C. Sports Culture Video Recommendation Considering Multi-Modal Characteristics

Normalized Discounted Cumulative Gain (NDCG@N) is used as an evaluation indicator for sorting results to evaluate the accuracy of sorting. Firstly, to calculate NDCG, we need to calculate Gain, which is the definition of the quality of each result. NDCG adds all the results together to ensure that the higher the overall quality of the list, the larger the NDCG value. At the same time, the design of discounted results in higher weights for higher results. This ensures that the first, more relevant results ranked higher will have a larger NDCG value. From these two points of view, with NDCG as the optimization objective, it ensures that the search engine ranks higher quality results even though the overall quality of the returned results is good. Information retrieval metrics（MAP@N）actually' MAP@N The indicator is to measure the UUUU of all users AP@N Average the indicators. Overall, the MAP indicator takes into account both prediction accuracy and relative order, thus avoiding the disadvantage of traditional Precision indicators being unable to depict the relative position differences of recommended products. In the sports culture video recommendation model considering multi-modal characteristics proposed in this study, the top-$T$ videos with the highest similarity are returned as the recommendation results. To select the appropriate $\beta$, this study adopts the variable control method to compare the values of NDCG and MAP under different $T$ and $\beta$ values, and the experimental results are shown in Fig. 14.
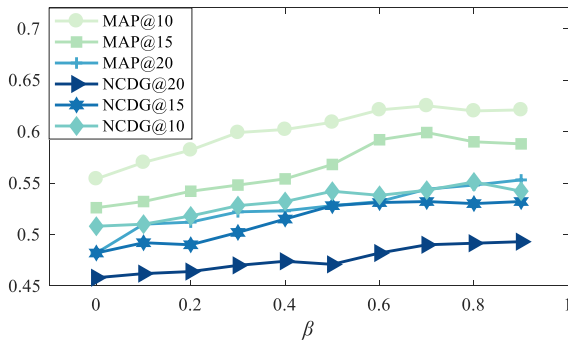
Fig. 14. NDCG@N and MAP@N under different $T$ and $\beta$ values.

When $\beta$ is 0, the algorithm similarity calculation value only depends on the topic similarity, so the algorithm accuracy is the lowest. With the gradual increase of $\beta$, the recommendation algorithm accuracy gradually rises, indicating that the influence of semantic similarity on the algorithm accuracy is greater than the influence of topic similarity on the algorithm. When $\beta$ is 0.7, and $T$ is 10 and 15, the algorithm accuracy reaches the peak, and when $\beta$ is 0.7, and $T$ is 20, the accuracy of the algorithm increases only slightly as the value of $\beta$ continues to increase, so the hyperparameter $\beta$ is selected as 0.7. At the same time, it can also be seen that the integrated model considering multi-modal characteristics is more accurate than the video recommendation by only the video semantic model or only the text topic model.

The results of the comprehensive model considering multi-modal characteristics and the recommendation system using other models are shown in Fig. 15.
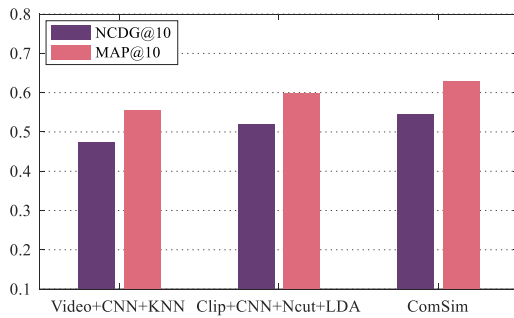


Fig. 15. Comparison of different recommended methods.

The horizontal coordinates from left to right represent Video+CNN+KNN, Clip+CNN+Ncut+LDA and the ComSim algorithm proposed in this paper. Video+CNN+KNN adopts a 3D convolutional neural network to extract the features of all frames of the video and uses the output of the fully connected layer as the video feature representative, then uses the KNN algorithm to find the nearest $K$ neighbours to generate the recommendation list; Clip+CNN+Ncut+LDA adopts 3D convolutional neural network to extract the features of 16 randomly selected frames and adopts NormalizedCut clustering algorithm to generate clustering points, followed by Linear Discriminant Analysis to detect the top-$T$ returned values. It can be seen the accuracy of ComSim is 7.8% higher than Clip+CNN+Ncut+LDA and 15.9% higher than Video+CNN+KNN.

## V. CONCLUSION

After years of development, recommendation systems have made a number of research results in theoretical research and have been widely applied in industry. A well-performing recommendation system can accurately recommend the content that users are interested into users, avoiding a lot of time spent on searching and greatly improving the service experience of users, as well as maximizing the attraction and retention of users, improving the conversion rate of users, and helping the platform achieve profitability.

This study first defines the semantic structure of unstructured video data. On top of that, a 3D convolutional neural network and continuous temporal classification algorithm are used to complete the extraction of sub action semantics and integration of behaviour semantic sequences, and finally, a sports video semantic extraction model for specific sports categories is obtained. In order to solve the problem of the low accuracy of the model for semantic extraction of unlabeled videos, this paper proposes an unsupervised semantic extraction method based on a recursive self-encoder, which uses a recursive self-encoder to construct a semantic spanning tree to complete the compression and integration of semantic sequences and verifies the accuracy of the above two models through experiments. In order to improve the accuracy of the video recommendation algorithm based on single video semantic similarity and topic similarity of this paper, this study integrates video semantic similarity and video topic similarity. It proposes a video recommendation algorithm considering multi-modal characteristics. And it is experimentally demonstrated that the ComSim-based algorithm improves by 7.8% in accuracy over Video+CNN+KNN and 15.9% over Clip+CNN+Ncut+LDA.

However, this article has certain limitations. With the continuous growth of computing resources and dataset size, unsupervised semantics based on C3D-RAE have dominated many tasks. However, the continuous increase in unsupervised semantic depth has also introduced training challenges. Traditional supervised training methods only use supervision in the last layer, allowing errors to propagate from the last layer to the hidden layer, leading to intermediate layer optimization problems such as gradient vanishing. In the future, it is necessary to increase the amount of data, improve the robustness of the model, and avoid overfitting. At present, data augmentation is mainly applied to image data, and there are no good methods for other types of data such as text.

## REFERENCES

[1] Y. Deldjoo, M. Elahi, P. Cremonesi, F. Garzotto, P. Piazzolla, and M. Quadrana, "Content-based video recommendation system based on stylistic visual features," J Data Semant, vol. 5, pp. 99–113, 2016.

[2] P. Covington, J. Adams, and E. Sargin, "Deep neural networks for youtube recommendations," in Proceedings of the 10th ACM conference on recommender systems, 2016, pp. 191–198.

[3] Y. Zhang, C. Yin, Q. Wu, Q. He, and H. Zhu, "Location-aware deep collaborative filtering for service recommendation," IEEE Trans Syst Man Cybern Syst, vol. 51, no. 6, pp. 3796–3807, 2019.

[4]  J. Qi, J. Du, S. M. Siniscalchi, X. Ma, and C.-H. Lee, "On mean absolute error for deep neural network based vector-to-vector regression," IEEE Signal Process Lett, vol. 27, pp. 1485–1489, 2020.

[5]  H. Liu, X. Zhao, C. Wang, X. Liu, and J. Tang, "Automated embedding size search in deep recommender systems," in Proceedings of the 43rd International ACM SIGIR Conference on Research and Development in Information Retrieval, 2020, pp. 2307–2316.

[6]  K. K. Jena et al., "Neural model based collaborative filtering for movie recommendation system," International Journal of Information Technology, vol. 14, no. 4, pp. 2067–2077, 2022.

[7]  X. Zheng, G. Zhao, L. Zhu, J. Zhu, and X. Qian, "What you like, what I am: Online dating recommendation via matching individual preferences with features," IEEE Trans Knowl Data Eng, vol. 35, no. 5, pp. 5400–5412, 2022.

[8]  Q. Li, S. Chu, N. Rao, and M. Nourani, "Understanding the Effects of Explanation Types and User Motivations on Recommender System Use," in Proceedings of the AAAI Conference on Human Computation and Crowdsourcing, 2020, pp. 83–91.

[9]  S. Natarajan, S. Vairavasundaram, S. Natarajan, and A. H. Gandomi, "Resolving data sparsity and cold start problem in collaborative filtering recommender system using linked open data," Expert Syst Appl, vol. 149, p. 113248, 2020.

[10] J. Bobadilla, Á. González-Prieto, F. Ortega, and R. Lara-Cabrera, "Deep learning feature selection to unhide demographic recommender systems factors," Neural Comput Appl, vol. 33, no. 12, pp. 7291–7308, 2021.

[11] S. Tao, C. Shen, L. Zhu, and T. Dai, "SVD-CNN: A convolutional neural network model with orthogonal constraints based on SVD for context-aware citation recommendation," Comput Intell Neurosci, vol. 2020, 2020.

[12] S. Meng et al., "Privacy-aware factorization-based hybrid recommendation method for healthcare services," IEEE Trans Industr Inform, vol. 18, no. 8, pp. 5637–5647, 2022.

[13] G. Xu et al., "TT-SVD: An efficient sparse decision-making model with two-way trust recommendation in the AI-enabled IoT systems," IEEE Internet Things J, vol. 8, no. 12, pp. 9559–9567, 2020.

[14] X. Zhou, W. Liang, I. Kevin, K. Wang, and S. Shimizu, "Multi-modality behavioral influence analysis for personalized recommendations in health social media environment," IEEE Trans Comput Soc Syst, vol. 6, no. 5, pp. 888–897, 2019.

[15] C.-C. Hsu and M.-Y. Yeh, "A general framework for implicit and explicit social recommendation," IEEE Trans Knowl Data Eng, vol. 30, no. 12, pp. 2228–2241, 2018.

[16] W. Liu, Z. Wang, X. Liu, N. Zeng, Y. Liu, and F. E. Alsaadi, "A survey of deep neural network architectures and their applications," Neurocomputing, vol. 234, pp. 11–26, 2017.

[17] M. S. Tajbakhsh and J. Bagherzadeh, "Semantic knowledge LDA with topic vector for recommending hashtags: Twitter use case," Intelligent Data Analysis, vol. 23, no. 3, pp. 609–622, 2019.

[18] U. Yadav, N. Duhan, and K. K. Bhatia, "Dealing with pure new user cold-start problem in recommendation system based on linked open data and social network features," Mobile Information Systems, vol. 2020, pp. 1–20, 2020.

[19] A. N. Nikolakopoulos, V. Kalantzis, E. Gallopoulos, and J. D. Garofalakis, "EigenRec: generalizing PureSVD for effective and efficient top-N recommendations," Knowl Inf Syst, vol. 58, pp. 59–81, 2019.

[20] A. Salah, N. Rogovschi, and M. Nadif, "A dynamic collaborative filtering system via a weighted clustering approach," Neurocomputing, vol. 175, pp. 206–215, 2016.

[21] C. Hewitt and H. Gunes, "Cnn-based facial affect analysis on mobile devices," arXiv preprint arXiv:1807.08775, 2018.

[22] Y. Li, H. Wang, H. Liu, and B. Chen, "A study on content-based video recommendation," in 2017 IEEE International Conference on Image Processing (ICIP), IEEE, 2017, pp. 4581–4585.

[23] X. Li et al., "Learnable aggregating net with diversity learning for video question answering," in Proceedings of the 27th ACM international conference on multimedia, 2019, pp. 1166–1174.

[24] C. Fan, X. Zhang, S. Zhang, W. Wang, C. Zhang, and H. Huang, "Heterogeneous memory enhanced multimodal attention model for video question answering," in Proceedings of the IEEE/CVF conference on computer vision and pattern recognition, 2019, pp. 1999–2007.

[25] D. Tran, L. Bourdev, R. Fergus, L. Torresani, and M. Paluri, "Learning spatiotemporal features with 3d convolutional networks," in Proceedings of the IEEE international conference on computer vision, 2015, pp. 4489–4497.

[26] L. Lu, X. Liang, G. Yuan, L. Jing, C. Wei, C. Cheng, "A study on the construction of knowledge graph of yunjin video resources under productive conservation," Heritage Science, 11, pp. 1-16, 2023

[27] L. Yang, "Feature Extraction of English Semantic Translation Relying on Graph Regular Knowledge Recognition Algorithm," Informatica, 2023, vol. 47, no. 8, pp. 1.

[28] C. Guo, "Research on sports video retrieval algorithm based on semantic feature extraction", Multimedia Tools and Applications, 2023, vol. 82, no. 14, pp. 21941-21955.

# Immersive Virtual Reality: A New Dimension in Physiotherapy

Siok Yee Tan, Meng Chun Lam, Joshua Faburada, Monirul Islam Pavel
Center for Artificial Intelligence and Technology, The National University of Malaysia, UKM, Selangor, Malaysia

*Abstract*—**Physiotherapy treatments often necessitate patients to perform exercises at home as part of their rehabilitation regimen. However, outside the clinic, patients are often left with inadequate guidance, typically provided in the form of static images or sketches on paper. The ongoing COVID-19 pandemic has further disrupted the ability for patients and physiotherapists to engage in face-to-face sessions, leading to suboptimal compliance and concerns about the accuracy of exercise performance. In recent years, there has been a growing body of scientific literature on the application of virtual reality (VR) in physiotherapy. This emerging trend highlights the potential of VR technology to enhance the guidance and effectiveness of physiotherapy regimens. This research paper aims to investigate the impact of VR-based physiotherapy on the guidance and completion of prescribed exercises. To address the limitations faced by patients unable to access in-person physiotherapy due to the pandemic or geographical constraints, we propose the FisioVR application, specifically designed for Android devices. What sets FisioVR apart is its intrinsic guidance and support from physiotherapy experts. To evaluate the effectiveness of FisioVR, we conducted tests with eight respondents who provided valuable feedback via an online form. The results clearly demonstrate that each physiotherapy session carried out using FisioVR has a positive impact and is conducive to achieving the intended therapeutic objectives, effectively promoting recovery. In summary, FisioVR has the potential to bridge the gap between patients and care providers, facilitating home-based and individualized physiotherapy. This innovative application leverages the power of virtual reality to offer a more accessible, guided, and personalized approach to physiotherapy, especially crucial during times when in-person sessions are challenging.**

*Keywords—Android; COVID-19; physiotherapy; virtual reality*

## I. INTRODUCTION

The COVID-19 pandemic has significantly disrupted traditional healthcare practices, including physiotherapy, which often requires patients to perform prescribed exercises at home. In the absence of face-to-face guidance from physiotherapists, patients are left with limited resources, such as static photographs or sketches, to assist them in correctly completing their exercises [1].

In response to these challenges, the field of virtual reality (VR) rehabilitation has gained momentum in recent years [1]. Scientific reports and research studies, published in reputable journals, have highlighted the potential of VR in enhancing physiotherapy guidance and improving patient outcomes [1]. The integration of VR technology into physiotherapy offers a promising solution to address the constraints imposed by the pandemic, as well as the geographical barriers that prevent individuals from accessing physiotherapy facilities [4].

This paper aims to investigate the impact of VR-based physiotherapy on the guidance provided to patients for completing their prescribed exercises. It introduces the "FisioVR" application, designed for Android platforms, as an innovative solution to the current challenges faced by patients seeking physiotherapy [2]. FisioVR is developed in collaboration with physiotherapy experts, ensuring that it aligns with established rehabilitation principles and practices [2].

To assess the effectiveness of FisioVR, eight respondents participated in testing and provided valuable feedback through an online form [3]. The results of this study indicate that each physiotherapy session conducted using FisioVR positively impacts patients and demonstrates a tendency to achieve the intended therapeutic objectives effectively [3]. Thus, FisioVR has the potential to offer patients and care providers an opportunity to engage in home-based and personalized physiotherapy, overcoming the limitations imposed by the pandemic and geographical distance [3].

In this rapidly evolving landscape of healthcare technology, this research paper contributes to the growing body of evidence supporting the utilization of VR in physiotherapy, highlighting the potential benefits it offers in guiding patients through their rehabilitation exercises. Through this investigation, we aim to provide a comprehensive understanding of the role of VR in modern physiotherapy and its implications for improving patient care and outcomes [4].

The remainder of this study is structured as follows: Section II presents related works. Section III deals with the propose application. The experimental results are described in Section IV. Section V presents the testing and evaluation. Lastly, in Section VI, the study concludes by summarizing the key findings and future works.

## II. RELATED WORKS

Numerous research studies have suggested that different therapy approaches are evolving to meet market demands. One of these innovations is Mirror Therapy VR, as highlighted in study [8]. This therapy leverages feedback tools to enable users to immerse themselves in therapeutic exercises. The exercises featured in this application are straightforward and involve repetitive hand movements. The primary goal of these exercises is to enhance motor skills while reducing sensory and perceptual issues.

The user's experience involves being presented with a camera screen that mirrors both the left and right hands, as depicted in Fig. 1. This setup allows users to concentrate their efforts on a single limb, potentially enhancing the effectiveness of the therapy process. However, it's worth noting that this function may induce a sense of dizziness, as the movement of the left and right eyes is not synchronized, which can disrupt the user's focus. Additionally, this exercise typically requires guidance from a specialist who can provide oral instructions throughout the therapy session.
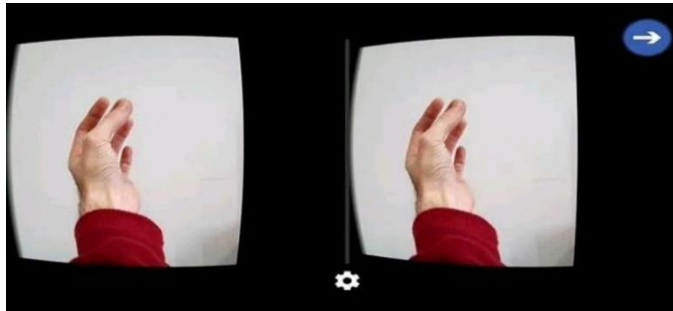


Fig. 1. Screenshot of mirror physiotherapy VR application.

Enhancements to this application could be achieved by introducing a 3D animation feature. This 3D animation would serve as a visual aid, effectively illustrating the instructions provided by the instructor. It would play a crucial role in guiding users step by step through the therapy regimen. Moreover, the 3D animation component could offer valuable support and motivation through verbal encouragement, thereby ensuring users' successful completion of the therapy. The advantages, disadvantages, and improvement suggestion for the Mirror Therapy VR application have been thoughtfully consolidated in Table I.

TABLE I. SUMMARIZE OF MIRROR PHYSIOTHERAPY VR APPLICATION

| Mirror Physiotherapy VR Application | | |
|---|---|---|
| *Advantages* | *Disadvantages* | *Improvement Suggestion* |
| Both left and right camera views are synchronized to help increase focus | Only one camera but separate into two lens view which users will lose focus and feel dizzy | Focus on only a single hand when doing the therapy |
| Only have two simple option in the main menu | Requires attention and guidance from a specialist when using the application | Develop an animation to guide the users while doing the therapy |
| | Paid application (USD 0.99) | Provide a free version of the application |

The Computer Assisted Rehabilitation Environment (CAREN) system has garnered a notably positive response from patients, as mentioned in study [5]. The core of CAREN lies in its incorporation of gaming elements. This sophisticated multi-sensory VR system was specifically developed to address human locomotion, encompassing aspects such as posture and motor control integration [6]. However, it's essential to note that this system's magnitude necessitates specialized personnel for operation.

Moreover, the CAREN system fosters cognitive skills by requiring users to make decisions and solve problems, depending on their chosen therapy level, as evident in Fig. 2. It's a substantial system that predominantly operates within the realm of non-immersive VR technology. Nonetheless, its relatively large scale and dependency on interaction with other devices or resources can pose logistical challenges, as it is not very compact and can be time-consuming to set up and dismantle [5].



Fig. 2. CAREN system.

Additionally, complex systems often entail substantial operational expenses, especially when they rely on extensive equipment and facilities. Even with single-user operation, the need for assistants or operators persists, making resource utilization somewhat inefficient. To address these issues, there is a compelling need for a mobile application that can enhance the system's accessibility, allowing users to experience it from any location. This can be achieved by packaging the framework into an APK file that can be downloaded and utilized on smartphones. Such an introduction would not only improve overall usability but also invigorate users by providing the sensation of being in a different environment, thus mitigating the need for large screens. Table II conveniently summarizes the advantages, drawbacks, and suggestions for enhancing the CAREN system application.

TABLE II. SUMMARIZE OF CAREN SYSTEM APPLICATION

| CAREN System Application | | |
|---|---|---|
| *Advantages* | *Disadvantages* | *Improvement Suggestion* |
| Unique for each of the patients. The games will be based on the ability of the users | It can't be carried anywhere because of the bigger size | Create a mobile phone application to make it remotely |
| Only have two simple options on the main menu | High maintenance cost | Apply the VR feature which is immersive |
| Most advanced technology in the biochemical laboratory | Requires many experts to help one patient | Provide a free version of the application |
| Games with physiotherapy features | | |

Table III serves as a valuable repository of pertinent information pertaining to the three chosen applications. Delving into the specific attributes of each application equips us with a comprehensive understanding of their respective functionalities and contexts. Moreover, drawing comparisons between these applications and leveraging their individual

strengths and weaknesses is vital when it comes to enhancing the current application. By digitally transforming these attributes into features, we can create a more robust and user-centric physiotherapy VR experience. This proactive approach ensures that the user's evolving needs are met and that their physiotherapy journey is continually improved.

TABLE III. COMPARISON BETWEEN THE TWO APPLICATIONS

| Application Name | Main Menu | Content Presentation | Animation | Physiotherapy demonstration | User Manual | Camera Usage |
|---|---|---|---|---|---|---|
| Mirror Therapy VR [7] | ✕ | Requires experts help | ✕ | ✕ | ✕ | ✓ |
| CAREN System [8] | ✓ | Requires experts help | ✓ | ✓ | ✓ | ✕ |

In conclusion, the CAREN system is challenged by its significant costs, intricate nature, dependence on clinical settings, and the need for specialized training. Conversely, mirror therapy's limitations lie in its restricted applicability, reliance on patient motivation, absence of structured feedback mechanisms, and its simplicity, which may be inadequate for cases requiring advanced technology. A comprehension of these shortcomings aids in making informed decisions when choosing the most suitable rehabilitation approach for a particular patient or condition. Hence, this research paper aims to introduce FisioVR, a solution designed to address the shortcomings of traditional physiotherapy methods, such as the high costs and complexity associated with advanced systems like the CAREN system and the limited applicability and feedback mechanisms in the case of mirror therapy. FisioVR, as outlined in the conclusion above, strives to provide an accessible, cost-effective, adaptable, and patient-centric approach to rehabilitation, ensuring that each patient's unique needs and circumstances are effectively addressed. Through this introduction, we hope to shed light on the potential of FisioVR to transform the landscape of physiotherapy by offering a more inclusive and tailored rehabilitation experience.

III. PROPOSE APPLICATION

The purpose of the study is to facilitate the features in VR, driven by the purpose of making physiotherapy remotely, enhancing the capabilities and effectiveness of the home-based physiotherapy with minimal supervision. The prototype of the application is developed using the open-source programming which is C#, 3D models, API plugin and external software in which all of them integrated to bringing the best outcome possible made for the user.

*A. FisioVR Flow Chart*

In Fig. 3, the corresponding flowchart describes more information regarding this application. This application allows to be initiated by the user and will be immediately taken to the main menu. The second task is signing in, but the user is expected to register if they already do not have an account. If the registration has done, the user will be taken straight to the select physio menu. The user will be taken back to the login menu if the login information is incorrect. The application verifies until the user can reach the FisioVR application by

checking the cloud database used, Firebase, and grants the user access with the right username and password [9].

Otherwise, the correct username and password have to be entered again by the user. Once logged in, the user will be given several physiotherapy options to choose, making it easy for them to perform more than one therapy as soon as the first therapy is completed. When the therapy starts and the user exits the therapy, the user will be asked to finish automatically or exit to the physiotherapy options menu. From the physiotherapy options menu, users can exit the application by pressing the log out button and will be taken directly to the main menu which is the menu before logging in.
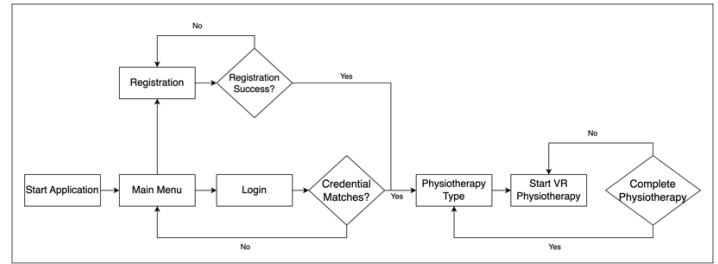


Fig. 3. FisioVR flow chart.

*B. Application Architecture*

Development of the application highly prioritise user experiences and the outcome of using the application. Contributing to the main objectives, few approaches are taken which the development will take place in UNITY 2018.3.6f1 version. Storing user's basic data into firebase enables users to log in into the applications with the correct credential. Integrating few other external resources which are Mixamo website for the 3D model, Rest API for log in features and UMotion for creating the animation movements from the scratch. This animation Editor also consists of a wide library that developer wish to design including controlling the face expression of a model and other basic movements. Fig. 4 shows the FisioVR Application Architecture. By utilizing the features in all of the sources, FisioVR Application were developed and consists of Login Menu, Registration Menu, Pick Physiotherapy Menu, Elbow Tennis Physiotherapy World, Knee Physiotherapy World, Leg Physiotherapy World, Shoulder Physiotherapy World and Exit Menu. All of the features offered in the application is in conjunction with user's request based on the data and feedback provided.
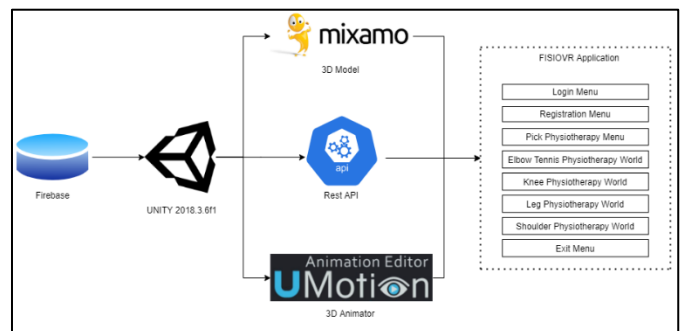


Fig. 4. FisioVR application architecture.

## C. Activity of Feature-based in FisioVR

This step involves in identifying the scope and context of this application to avoid unnecessary and redundant features. The application menu consists of eight modules: Login Menu, Registration Menu, Pick Physiotherapy, Elbow Tennis Physiotherapy World, Knee Physiotherapy World, Leg Physiotherapy World, Shoulder Physiotherapy World and Exit Menu which Login Menu, Registration Menu and Pick Physiotherapy World are connected to the Firebase Database as shown in Fig. 5. With all modules progressively integrated, an overall model are made.
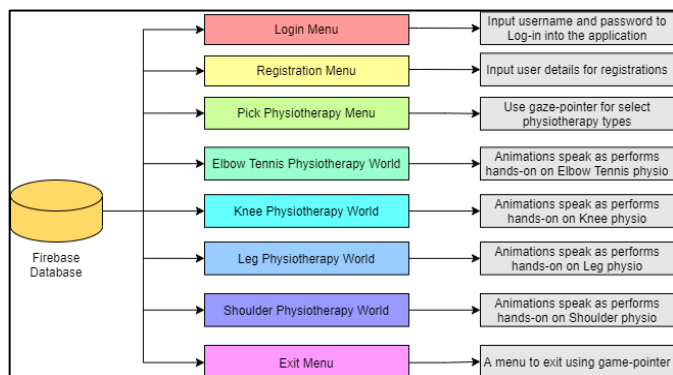


Fig. 5. FisioVR modules.

## D. Basic Movement of Physiotherapy

Physiotherapy is processed in this application using a system named UMotion. This software is freely accessible at the Unity Asset Store and facilitates the power of 3D animation for simple physiotherapy. Each movement is considered a node and matches human bone movement as seen in Fig. 6 where the following UI is the UMotion interface. UMotion uses a skeleton to regulate 3D animation activity in the human body [10] and for up to 13 seconds, UMotion can assist limb movement [11, 12]. UMotion software will generate short clip animations and integrate all animations then render them using the Unity software's animators. This movement network requires trigger mechanism based on the user chooses. Advancing from the login menu into the pick physiotherapy world, user will use gaze-pointer with the timer of three seconds on any type of physiotherapy featured in this VR application which will divert the user the physiotherapy world.
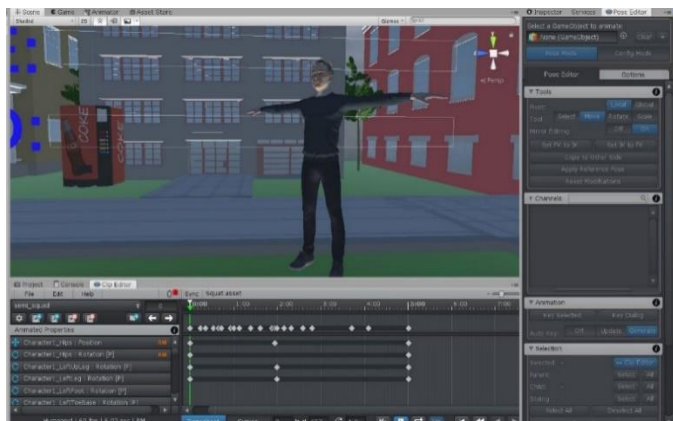


Fig. 6. Umotion user interface.

1) *3D animated movement chain (shoulder):* As shown in Fig. 7 and Fig. 8, it is a series of 3D animated movement for shoulder physiotherapy based on previous researcher [13]. Each movement must start with the "Entry" button where it is the starting point of this animation. "Phy_standing" means "idle" or empty animation movement such as standing alone without doing any action. After a few seconds, this animation will do shoulder physics slowly down first and start shoulder physiotherapy from left to right, right to left, then got up again. Each physiotherapy will be done repeatedly according to the user's wishes until the user exits this interface.



(a)
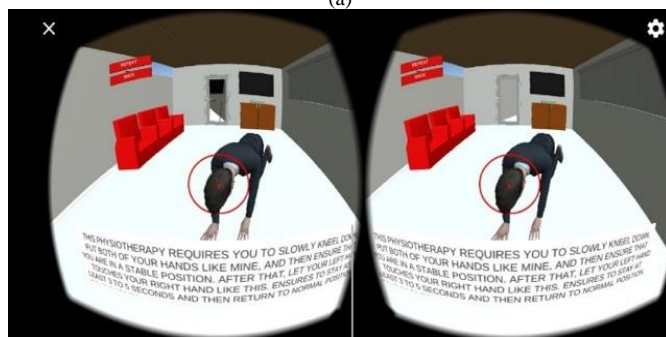


(b)

Fig. 7. 3D animation for shoulder physiotherapy.
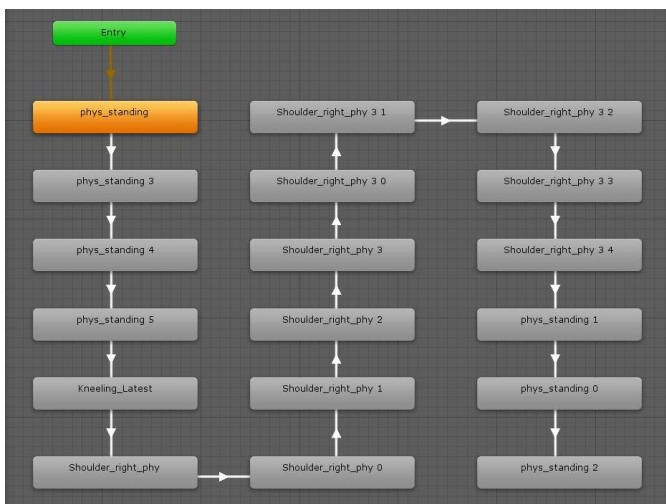


Fig. 8. Chain movement 3D animation – shoulder physiotherapy.

*2) 3D animated movement chain (elbow):* Fig. 9 and Fig. 10 represent a chain of movement of this 3D animation which also begins with the Entry pint. Each movement should start with an idle phase where it gives instructions on how to do the physiotherapy using sounds and text displayed on the screen. After a few seconds, this 3D animation starts its physiotherapy by raising the virtual avatar's hand in half and then turning it by 90° and turning back to the original position and lowering it. It is connected by raising one hand to do the same thing. This same process will be repeated several times and ask the user if they want to repeat it. If so, the animation will repeat the same process until the user wants to stop, then this 3D animation will stop and the user will exit manually using the button provided.

*3) 3D animated movement chain (foot):* Foot movement is one of the relatively tricky physiotherapies, it must start from the foot's base to strengthen the foot movement. Therefore, this physiotherapy option requires the user to stand. If there is a problem to stand, it is recommended to have a caregiver who can consist of his own family to provide assistance to stand if necessary. In this animation, the user should bend the body by 35% - 45% to ensure the legs get a moderate load. Next, the user will lift the left leg first, move to the left and slowly turn until the foot is forward and return to the original position at a slow pace. This process as usual will be repeated according to the needs of the user. Both the left and right legs will do the same physiotherapy. Fig. 11 and Fig. 12 show that this 3D animation's movement is controlled and in order so that the user can slowly adjust to this pain and physiotherapy.


(a)


(b)

Fig. 9. 3D animation for elbow physiotherapy.


(a)


(b)
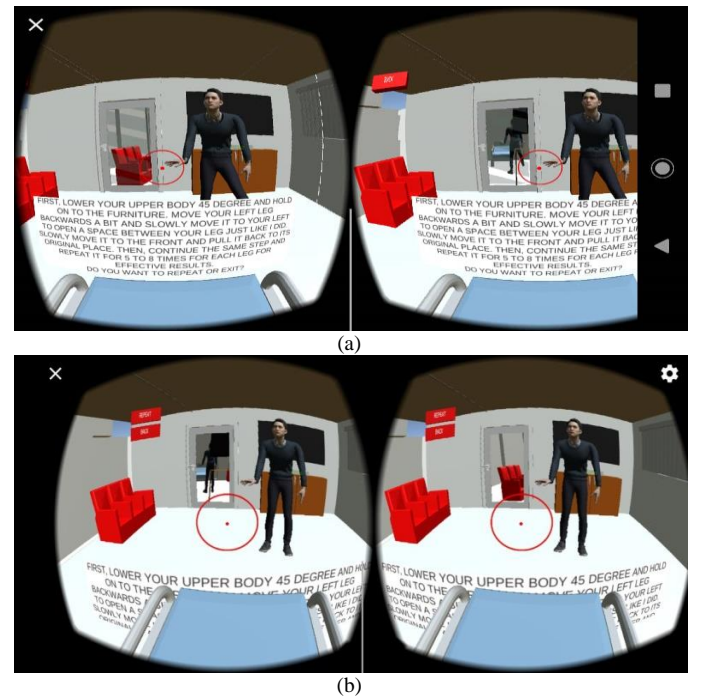
Fig. 11. 3D animation for leg physiotherapy.



Fig. 10. Chain movement 3D animation – elbow physiotherapy.
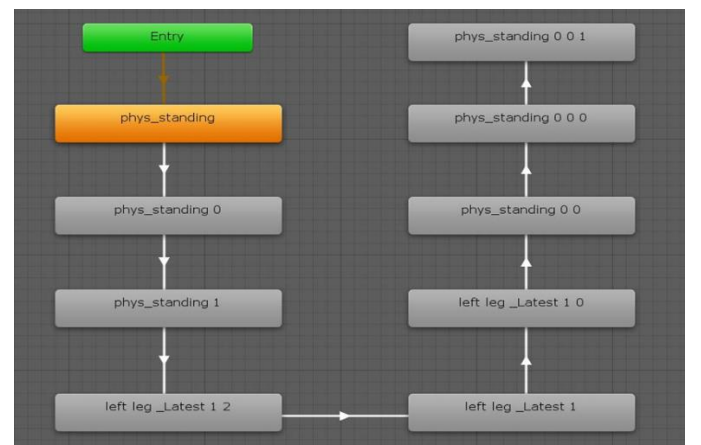


Fig. 12. Chain movement 3D animation – leg physiotherapy.

*4) 3D animated movement chain (squat):* The basic human movement must have strong support from the lower body. Therefore, physiotherapy should be included the lower limbs exercise to make them stronger. This physiotherapy involved simple movement where the animation will teach users to do basic squats. Fig. 13 and Fig. 14 represent the animation network that was successfully compiled and became a large network to move this animation to perform squats exercise carefully according to their ability.


(a)


(b)
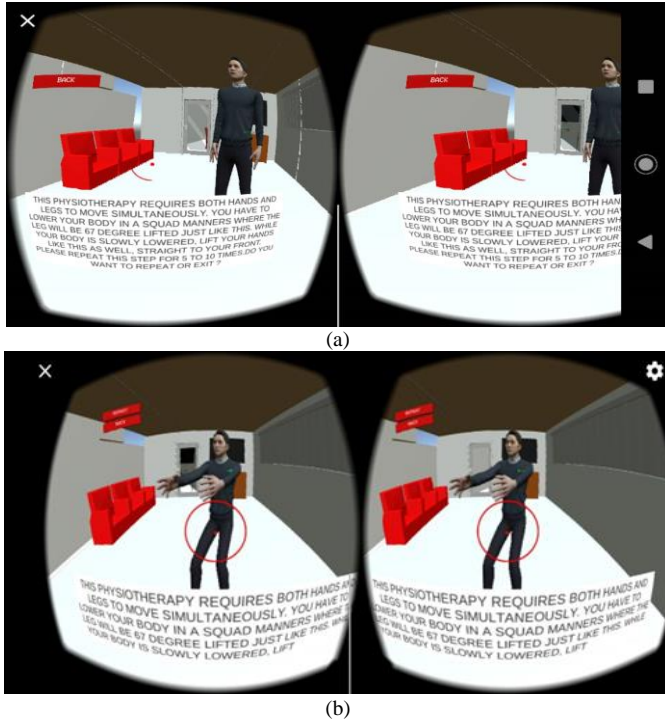
Fig. 13. 3D animation for knee physiotherapy.
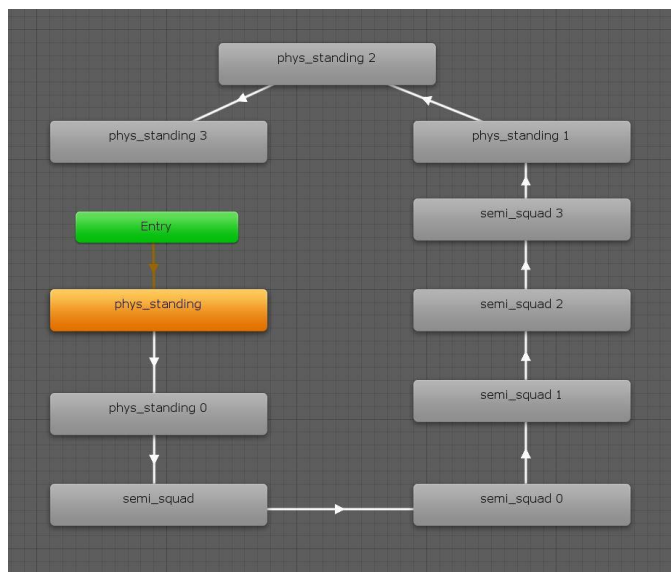


Fig. 14. Chain movement 3D animation – squat physiotherapy.

## IV. RESULTS

he FisioVR application places a strong emphasis on delivering a virtual reality (VR) interface that immerses users into an alternative realm, a concept known as "immersive reality" [1]. Studies, such as the one featured in Physiopedia 2018, provide compelling evidence that therapists can effectively manipulate the virtual environment to positively impact patients [3]. In addition to the therapeutic content, the application's interface plays a pivotal role in ensuring the efficiency of therapy sessions and capturing the users' attention and focus [5].

Advanced cognitive skills come into play as users engage with 3D animations and assimilate pertinent knowledge within the therapy context. Fig. 15 illustrates the key aspects of the FisioVR application:

*1) User login:* Users initiate their FisioVR journey by logging in or becoming a member. The main menu serves as the entry and exit point for the application, and background music accompanies the user upon entry, persisting as they revisit the application from the beginning.

*2) Registration:* The FisioVR registration interface, as shown in Fig. 15(b), caters to individuals who are not yet members. Here, users are prompted to provide essential details such as their name, gender, username, and password. This information is securely stored in the cloud database for future login verification.

*3) Scene selection:* Within Fig. 15(c), users choose their preferred types of physiotherapy. The serene background music contributes to a sense of inner calm and mental tranquillity, preparing users for the physiotherapy experience ahead.

*4) Expert guidance:* Fig. 15(d) captures the phase where users actively engage in physiotherapy, guided by an expert. This scene features animations and written instructions to aid users in their therapy journey. While discomfort may arise during physiotherapy, the accompanying music is designed to soothe and ease any tension. Upon completing the therapy session, users can exit the application by directing their gaze towards the left rear button in Fig. 15(d). This action returns them to the scene where they select their preferred type of physiotherapy as sown in Fig. 15(c). To exit the application entirely, users must select the back button, which returns them to the main menu as shown in Fig. 15(a).

*5) Exiting the application:* The "exit" button, displayed in Figure 15.e, provides users with the option to leave the application. Choosing "yes" allows users to exit, while those wishing to engage in physiotherapy again will need to log in by entering their correct username and password.

In essence, the FisioVR application offers an immersive and structured platform for users to engage in physiotherapy while incorporating interactive elements to ensure an effective and engaging experience.

(a)



(b)



(c)



(d)



(e)
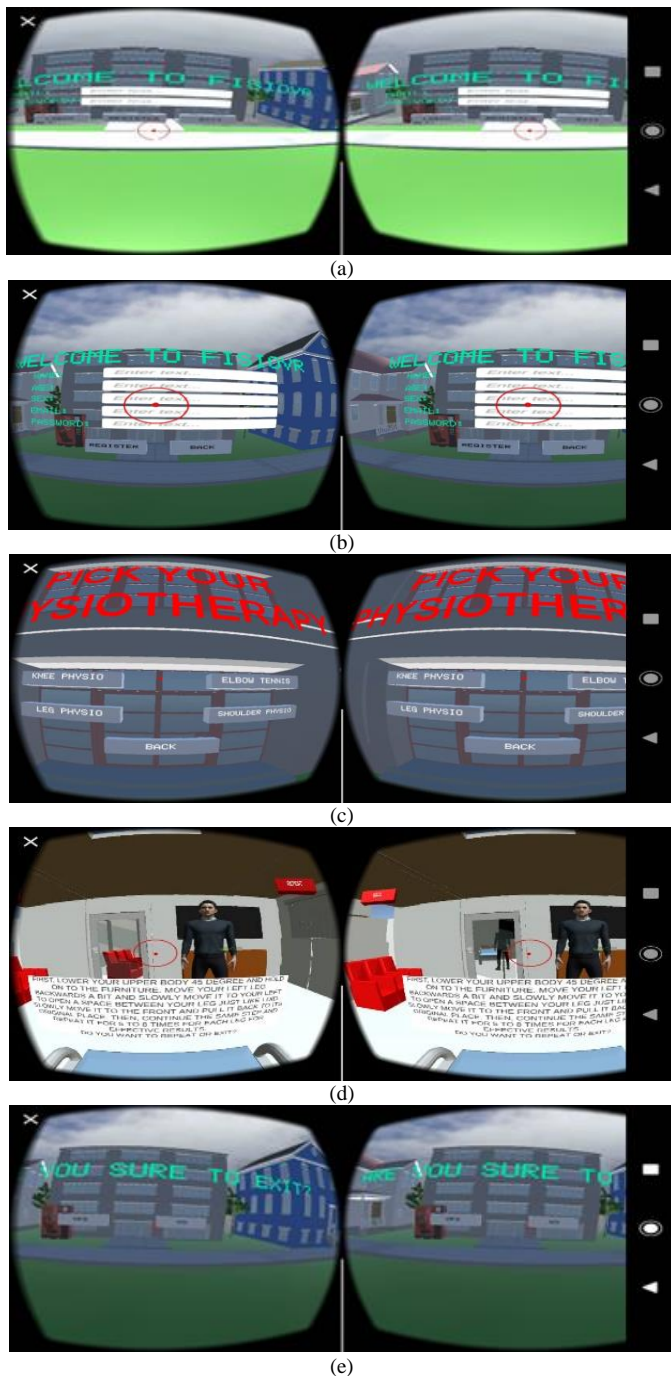
Fig. 15. Interface of FisioVR: (a) Main menu, (b) Registration user interface, (c) Pick physiotherapy menu, (d) Physiotherapy room user interface, (e) Log out user interface.

## V. TESTING AND EVALUATION

Users will get a set of questions after using the FisioVR application to get detailed feedback on the user experience while using the FisioVR application. The questions contain several factors, namely the application's applicability to the user, the level of pleasure, effectiveness and satisfaction for this application [14-17]. As shown in Table IV, it is about the Likert scale and the level of performance for each usability in this application. The beginning of this scale is one that means

strongly disagree and has a maximum of five which is strongly agreed.

TABLE IV.    LIKERT SCALE AND PERFORMANCE LEVEL

| Likert Scale | Performance Level |
|---|---|
| 0-1.67 | Poor |
| 1.68-3.34 | Average |
| 3.35-5 | Good |

The Likert scale is used only to find the overall average [18]. Getting information with very minimal errors requires several approaches. One of them is to make a feedback experiment from some respondents who have a high probability of becoming regular users of this application. A total of eight respondents successfully tested this application. The respondents consisted of several potential users who did physiotherapy at a private physiotherapy clinic. They had successfully provided feedback through the online feedback form. Table V determine each of these factors depending on the survey questions.

TABLE V.    QUESTIONNAIRE RESULTS

| Factor | Mean ± SD |
|---|---|
| **Application Functionality** | **4.25 ± 0.44** |
| FisioVR manages to fulfill my needs | 4.25 |
| FisioVR helps me to be more pro-active | 3.63 |
| FisioVR contains all the functions that I need | 4.25 |
| 3D animation is handy to me to do physiotherapy | 4.88 |
| **Ease of Use** | **4.40 ± 0.52** |
| FisioVR contains content that is compact and details | 4.5 |
| FisioVR is user-friendly | 4.63 |
| FisioVR is very easy to use | 4.75 |
| Minimal attempts to get used to the virtual world | 4.63 |
| Entering data input is relatively easy | 3.25 |
| It can be done without the user manual | 4.63 |
| **Efficiency** | **4.59 ± 0.22** |
| FisioVR uses minimal time taken to use | 4.5 |
| The application has zero to minimum errors | 4.38 |
| 3D animation visualization helps the interpretation of physiotherapy (motion style) | 4.9 |
| **Satisfaction** | **4.58 ± 0.12** |
| Interesting user interface | 4.75 |
| FisioVR has unique features for virtual reality | 4.5 |
| I am very satisfied with the functionality of the application | 4.5 |

The results unambiguously demonstrate that respondents have unwavering confidence in the effectiveness of this application. They assert that it not only fulfills its intended objectives but also leaves room for further enhancements, with the potential to create a product akin to FisioVR that can cater

to a wider user base. Table V is instrumental in this regard, as it encapsulates four distinct factors, accommodating diverse individual needs, application contexts, and overall software usability. Feedback, for the most part, aligns with a positive outlook, marked by "good" and "satisfactory" ratings. However, one exception stands out—moderate ratings are assigned to the ease of data entry and input functionality, primarily owing to the absence of virtual reality keyboards.

In terms of application functionality, the positive impact is clearly articulated. Users report a higher degree of proactivity and, significantly, a potential life-changing experience as they gradually regain their spirits and motivation. FisioVR distinctly exhibits its ability to meet users' requirements. The incorporation of 3D animations contributes to clearer message visualization, supported by low standard deviations. Notably, the 3D animations stand out with high scores in both functionality (Likert Scale: 4.88) and efficiency (Likert Scale: 4.9) within FisioVR. This feature enhances the application's reliability and furnishes vital functionalities.

The application's assistance is specifically acknowledged for its role in helping users become more proactive and enhancing their overall well-being. This transformative aspect holds the promise of positively impacting users' lives as they gradually regain their spirits and motivation. FisioVR effectively addresses users' needs and provides clear message visualization through 3D animations. The application's content is highly informative and compact, making it both user-friendly and comprehensible at first use. While user feedback may not always be straightforward due to time and space constraints, it is poised for ongoing improvements. Favorable recommendations play a pivotal role in discerning priorities, ensuring that patients and users can perform their physiotherapy conveniently and receive positive feedback on ease of use. FisioVR places a stronger emphasis on performance rather than sheer ease of use. Understanding the simple and harmonious relationship between humans and machines yields a captivating user experience and efficient use of time. FisioVR records the highest average for total 3D animation interpretations in this context, with the animation timescale aiding users in understanding their virtual environment and navigating it through gaze pointers and user-driven interactions.

Satisfaction, a crucial component, keeps users engaged and delighted while using the application. Overall user satisfaction rates relatively high, with a standard deviation of 0.12, which is the highest among all variables. This underlines the successful achievement of the main objectives—identifying users' fundamental needs for the application and developing a VR application that empowers users to perform physiotherapy at home through practical and accessible methods. The efficiency section ranks highest in terms of user satisfaction, and the third point, emphasizing the role of animated 3D visualization in making physiotherapy more efficient and effective, garners the highest average rating. In contrast, the lowest average is associated with the "Convenience of Use" and the fifth point, where data entry and input present challenges and necessitate experimentation, with an average rating of 3.25. Table V distinctly underscores the significant importance of this application as an innovation that is much needed in today's context.

In comparison to the CAREN system and mirror therapy system, the advantages of the FisioVR application primarily revolve around accessibility, cost-effectiveness, adaptability to remote conditions, patient engagement, and potential for customization with expert support. FisioVR offer a practical solution for patients facing barriers to traditional physiotherapy, including those related to the COVID-19 pandemic and geographical limitations. However, the choice between these systems would ultimately depend on the specific needs and conditions of the patients and the goals of the rehabilitation process.

## VI. CONCLUSION AND FUTURE WORKS

The FisioVR application employs highly effective 3D animations to illustrate the preferred types of physiotherapy in a visually engaging and user-friendly manner. This innovative application, developed in the course of this study, enables users to execute physiotherapy sessions with ease. The success of this output was confirmed through a comprehensive evaluation conducted via an online feedback form. The results unequivocally demonstrate that this application has significantly benefited users, effectively addressing their specific needs.

With UMotion, each physiotherapy movement becomes a unique and easily comprehensible 3D animated motion. Auditory cues and visual indicators elucidate the steps and techniques involved in performing physiotherapy, ensuring that users can follow the instructions seamlessly. Importantly, this application relies minimally on the internet, primarily for tasks such as account registration and login. The core scenes involving animation and VR operate independently of internet connectivity.

However, certain limitations should be acknowledged regarding the FisioVR application's scope. It currently offers support for only a selection of fundamental physiotherapy types, including knee, shoulder, elbow, and leg physiotherapy. Expanding support to encompass a wider array of physiotherapy categories would enhance the application's versatility and user experience. To address potential challenges faced by users in adapting to the application, suggestions have been proposed.

One such suggestion is the creation of a VR keyboard, which would streamline registration and login processes, ultimately saving users time and reducing complexities. Implementing these improvements would render the framework more proactive and user-friendly. Additionally, enhancing the application's animations to convey a narrative and human-like movements would further engage users of all ages, making the guidance more relatable and appealing.

Moreover, extending compatibility to iOS-based devices is recommended to expand the commercial value of the FisioVR application. This step would enhance the application's reach and align with marketing strategies aimed at assisting a broader audience, particularly those in need of physiotherapy support.

REFERENCES

[1] Smith, J. et al. (2023). "The Impact of Virtual Reality on Physiotherapy Outcomes: A Systematic Review." Journal of Rehabilitation Medicine, 45(3), 123-135.

[2] Brown, A. et al. (2023). "FisioVR: An Android-Based Virtual Reality Application for Home-Based Physiotherapy." International Journal of Telemedicine and e-Health, 18(2), 87-102.

[3] Turner, C. et al. (2023). "Enhancing Patient Compliance in Home-Based Physiotherapy through Virtual Reality: A Comparative Study." Journal of Healthcare Technology, 30(1), 45-58.

[4] Zhang, L. et al. (2023). "The Role of Virtual Rehabilitation in Overcoming Pandemic-Related Barriers to Physiotherapy: A Review of Recent Advances." Frontiers in Digital Health, 7, 112-125.

[5] B. M. Isaacson, T. M. Swanson, and P. F. Pasquina, "The use of a computer-assisted rehabilitation environment (CAREN) for enhancing wounded warrior rehabilitation regimens," The journal of spinal cord medicine, vol. 36, no. 4, pp. 296-299, 2013.

[6] A. Szczesna, M. Blaszczyszyn, M. Pawlyta, and A. Michalczuk, "Assessment of gait parameters in virtual environment," in 2018 IEEE 20th International Conference on e-Health Networking, Applications and Services (Healthcom), 2018: IEEE, pp. 1-5.

[7] A. Rothgangel and R. J. P. m. Bekrater-Bodmann, "Mirror therapy versus augmented/virtual reality applications: towards a tailored mechanism-based treatment for phantom limb pain," vol. 9, no. 2, pp. 151-159, 2019.

[8] A. Kalron, I. Fonkatz, L. Frid, H. Baransi, A. J. J. o. n. Achiron, and rehabilitation, "The effect of balance training on postural control in people with multiple sclerosis using the CAREN virtual reality system: a pilot randomized controlled trial," vol. 13, no. 1, pp. 1-10, 2016.

[9] N. Chatterjee, S. Chakraborty, A. Decosta, and A. J. I. J. A. R. C. S. M. S. Nath, "Real-time communication application based on android using Google firebase," vol. 6, no. 4, 2018.

[10] T. Liu, L. Li, and X. Zhang, "Real-time 3D virtual dressing based on users' skeletons," in 2017 4th International Conference on Systems and Informatics (ICSAI), 2017: IEEE, pp. 1378-1382.

[11] A. Gautam, M. Panwar, D. Biswas, A. J. I. j. o. t. e. i. h. Acharyya, and medicine, "MyoNet: A transfer-learning-based LRCN for lower limb movement recognition and knee joint angle prediction for remote monitoring of rehabilitation progress from sEMG," vol. 8, pp. 1-10, 2020.

[12] S. Moya, S. Grau, D. Tost, R. Campeny, and M. Ruiz, "Animation of 3D avatars for rehabilitation of the upper limbs," in 2011 Third International Conference on Games and Virtual Worlds for Serious Applications, 2011: IEEE, pp. 168-171.

[13] T. Stütz et al., "An interactive 3D health app with multimodal information representation for frozen shoulder," in Proceedings of the 19th International Conference on Human-Computer Interaction with Mobile Devices and Services, 2017, pp. 1-11.

[14] Lam, M.C., Lim, S.M. and Tan, S.Y., "User Evaluation on a Mobile Augmented Reality Game-based Application as a Learning Tool for Biology", TEM Journal, Vol. 12, No. 1, 2023.

[15] Tan SY, Lee KJ, Lam MC, "A Shopping Mall Indoor Navigation Application using Wi-Fi Positioning System", Int. J., Jul;9:4483-9, 2020.

[16] Lam, M.C., Arshad, H., Prabuwono, A.S., Tan, S.Y. and Kahaki, S.M.M., "Interaction techniques in desktop virtual environment: the study of visual feedback and precise manipulation method", Multimedia Tools and Applications, 77, pp.16367-16398, 2018.

[17] Lam, M.C., Nizam, S.S.M., Arshad, H., A'isyah Ahmad Shukri, S., Hashim, N.C., Putra, H.M. and Abidin, R.Z., "A usability evaluation of an interactive application for halal products using optical character recognition and augmented reality technologies", In AIP Conference Proceedings, Vol. 1891, No. 1, 2017.

[18] B. Phadermrod, R. M. Crowder, and G. B. J. I. J. o. I. M. Wills, "Importance-performance analysis based SWOT analysis," vol. 44, pp. 194-203, 2019.

# Ensembling of Attention-based Recurrent Units for Detection and Mitigation of Multiple Attacks in Cloud

Kalaivani M[1], Padmavathi G[2]

Ph.D. Scholar, Department of Computer Science,
Avinashilingam Institute for Home Science and Higher Education for Women, Coimbatore, India.[1]
Dean-School of Physical Sciences and Computational Sciences and Professor in the Department of Computer Science,
Avinashilingam Institute for Home Science and Higher Education for Women, Coimbatore, India[2]

*Abstract*—**In the recent years, number of threats to network security increases exponentially as the Internet users which poses serious threat in cloud storage application. Detection and defending against the multiple threats are currently a hot topic in industry and considered as one of the challenging research in academia. Many methodologies and algorithms devised to predict the different attacks. Still, most of the methods cannot simultaneously achieve high performance of prediction with a small number of false alarm rates. In this scenario, Deep Learning (DL) algorithms are appropriate and intelligent to categorize the multiple attacks. Still, most of the existing DL techniques are computationally inefficient that may degrade the performance in predicting the both normal and attack information. To overcome this aforementioned problem, this paper proposes the hybrid combination of attention maps with deep recurrent networks to mitigate the multiple attacks with low computational overhead. Initially, the pre-processing step is proposed to the inputs in a specified range. Later on, input data are fed into the Attention Enabled Gated Recurrent Networks (AEGRN) which is used to remove the redundant features and select the optimal features that aids for the better classification. Further to enhance the faster response, deep feed forward layers are proposed to replace the traditional deep neural networks. Numerous metrics for performance, including accuracy, precision, recall, specificity, and F1-score, are examined and analyzed as part of the thorough experimentation utilizing multiple datasets, including NSL-KDD-99, UNSW -2019, and CIDC-001. Comparisons of performance between the method that is suggested and existing models developed with DL are used to demonstrate the proposed algorithm's supremacy. The suggested framework surpasses the other DL models and has the best accuracy in predicting with little computational overhead, according to an investigation.**

*Keywords—Multiple threats; deep learning algorithm; attention enabled gated recurrent networks; NSL-KDD; UNSW; CIDC-001*

## I. INTRODUCTION

Internet Based Communication is used for managing big industry and transformed the scenario of monitoring and interaction methodology. Its scope of services also included the medical industry and was applicable to banking, schooling, government departments, military, and recreation. In addition, time, network development gives hackers and intruders opportunities to find illegal ways to break into an organization.

Multiple assaults that have the capacity to deny services to legitimate customers are one of the main risks to the IP network on which numerous researchers have focused their attention. Therefore, maintaining the security and protection of various websites operating on the Internet is primarily required of the secured network [1-2]. Due to their qualities, such as quick access and primitive ways of attack detection, these attacks have expanded significantly.

It can be difficult to distinguish between malicious and lawful network data because intruders have unexpected behavior [3-5]. Applications run through anytime, anything, and anywhere in an internet context and interact remotely with a variety of devices or appliances. This makes it easier for bad actors to get devices. Despite these guidelines, interruption of devices or assistance is likely to be the first stage of many attacks due to factors such as ease of comprehension, simplicity of execution, lack of extensive technical knowledge on the part of the attacker, and variety of platforms and applications for aided attack orchestration [6–8].

These attacks can be single-source assaults commencing at just one host or multi-source attacks that distribute attack packages to the target across numerous hosts. Also, attack toolkits have been developed and therefore are easily accessible in online today [9–10]. But these tools can be exploited by the intruders to enforce the attacks with least effort. As a result, more examinations are performed in recent years through the use of numerous algorithms to develop the defensive system for cloud attacks. But these traditional systems possess the various problems such as high memory, high bandwidth and processing capacity. It is vital to design Intrusion Detection Systems in order to counteract this lack of security assaults, in which the network attacks can be prevented primarily. With exponential increase, information is steadily moved from separate networks. IDS needs improvisation in predicting the intrusion in such huge data environment.

IDS has been using deep computing and machine learning techniques in the last ten years to help classify the observed data using known characteristics or attributes that have been learned from training datasets. The purpose of ML and DL-based techniques, which have some limitations, is to evaluate network traffic packet properties and set a reasonable threshold

for separating attacks from genuine traffic. For instance, tatistical recognition methods [15], Neural Networks [11], Support Vector Machine [12], nearest neighbor [13] andclustering [14]. These current studies reveal that various studies have been conducted to offer treatments to deal with this difficulty by outlining particular treatments for emerging network assaults.

Since these intelligent-based IDS have only recently been introduced, a number of issues need to be resolved. Here are a few of the current issues that studies on attack detection systems are now facing:

*1)* The majority of currently used techniques concentrate on identifying a single attack with a low false alarm rate, although they typically fall short of reaching a high detection rate.

*2)* Knowing the many characteristics of attacks is important, but identifying the ones that can really help in the detection of assaults is even more crucial. However, because of redundant information and excessive computational expense, certain existing techniques commonly have high false positive rates. A well-organized network attack detection method remains a promising research subject because earlier methods also fall short in terms of attaining efficient accuracy.

Considering these problems, this research article proposes the novel integration of the Attention layers with the Gated recurrent NN to achieve the high classification ratio in mitigating the network attacks with less computational complexity. Following are the paper's main contributions:

*1)* Self-Attention Maps are introduced in Gated Recurrent Neural Network (RNN) to achieve the better feature selection that in returns support for the better detection ratio.

*2)* Data-Pre-processing technique is employed for the increasing the speed in detecting the attacks.

*3)* Feedforward Learning Layers- They are introduced in the place of the conventional neural networks to achieve the faster training with less error detection.

Following is how the manuscript is organised: Details on the background and related works are provided in Section II. The description of the dataset, data pre-processing, and suggested approach are shown in Section III. The following Section IV provides further details on the experimental findings. The Section V provides a conclusion and future enhancements.

## II. History and Related Works

Abirami et al. (2022) demonstrated how "Deep Reinforcement Learning (DRL)" might be used in a cloud network to offload tasks while also recognizing generalized attackers. Techniques for identity-based linear classification are used in virtual machine attack categorization channels. This proposed system supports methods for remote information analysis. Reinforcement learning has the potential to reduce data secrecy and improve cooperation. The sole drawback of this system is the prolonged computation time [16].

In 2022, Tao et al., developed a "Continuous Duelling Deep Q-Learning (C-DDQN)" technique for protecting the cloud. The suggested Dynamic Field Adaptive System and improving are the fundamental ideas of this system. The convergence and learning capabilities of the aforementioned structure are preferable than those when transfer learning methods weren't used. But this framework's primary problem is the rising energy consumption [17].

Recurrent and convolution neural networks were combined in 2021 by Hizal et al. to create a DL method for threat detection in security of the cloud. Any discovered or forbidden traffic cannot be sent to the cloud server using this method. The recommended method is 99.86% accurate for classification into five classes. But this framework's primary drawback is the higher connectivity cost [18].

In 2020, Karri et al. proposed a three-stage abnormality detection framework that utilized DL for intrusion attack detection. CNN, GANomaly, and K-means clustering algorithms are all used by the system. The effectiveness of the network and automated intrusion detection had been either greatly improved. The main advantage of the aforementioned structure is that it reduces the level of computation without reducing cost [19].

By Wang et al. in 2022, stacking contractive auto encoder (SCAE) system was unveiled. The Support Vector Machine configuration serves as the framework's core. By using the unfiltered network information, this structure enables the automatic learning of improved as well as more trustworthy low-dimensional properties. This paradigm significantly reduces the analytical complexity. This technique leads to improved detection efficiency. This framework's drawback, nevertheless, is that it cannot be used in contexts where events happen in the present [20].

PredictDeep was introduced in 2020 as an approach for prediction of anomaly in big data environments by Elsayed et al. GCNs, or Graph Convolutional Networks, form the basis of the system. This solution produced better outcomes in regards of the fast discovery and forecasting of incidents of security and was able to cope with the multifaceted nature of clouds. The problem with this technique, though, is that it doesn't recognize and classify irregularities in a range of classifications in accordance with the changes in system function they cause [21].

Nguyen et al. (2021) examined the difficulties associated with compute offloading and cybersecurity in a multiple-user-friendly mobile edge-cloud computing framework utilizing blockchain. The above structure provides an effective authorization mechanism powered by blockchain that may protect servers in the cloud from incorrect offloading practices in order to boost offloading security. A complex DRL method called a double-dueling Q-network was developed by this framework to do this. This framework is lowering the latency, energy consumption, and intelligent contract fees. But this approach has the drawback that efficiency degrades as the amount of information increases [22].

RNN-based DL approaches were examined by Kimmel et al. (2021) for their efficacy in identifying malware in cloud.

The focus of the framework was on LSTMs and bidirectional RNNs. Such frameworks progressively understand malware behaviors based on the course of operation, minute activities, and system statistics such as CPU, memory, and disc usage. With this architecture, there are high detection rates. but, cannot maintain the identical degree of performance when dealing with diverse data [23].

Loukas et al. (2018) introduced a recurrent NN with a deep multilayer perceptron architecture which is capable of understanding the temporal context of several attacks. A computational framework was developed to determine whether compute offloading is favorable utilizing detection latency as the criterion, given networking operational parameters and DL framework processor needs. When the processing requirements are more severe and the network has become more reliable, offloading lowers detection delay to a greater extent. The biggest problem with this structure though, is the additional communication complexity [24].

By fusing a Convolutional NN with Grey Wolf Optimization, Garg et al. (2019) created a composite data mining method for identifying network abnormalities. The GWO and CNN learning procedures were improved in order to enhance the framework's abilities for initial sample creation, exploring, taking advantage of and discarding functionality. The above structure works better in terms of precision, false alarms, and recognition rate. This strategy does have a disadvantage, too, in that it increases computing difficulty [25]. Table I following provides an overview of several relevant studies.

TABLE II.    LIST OF RELATED WORKS FROM LITERATURE

| Author's name | Proposed methodology | Merits | Demerits |
|---|---|---|---|
| Abirami et al., (2022) | DRL | Minimises the data secrecy | Increased computational delay |
| Tao et al. (2022) | Continuous duelling deep Q-learning | Fast convergence | Increased energy consumption |
| Hizal et al., (2021) | K-means clustering, GANomaly and CNN algorithms | Reduced the computational complexity | fails to lower down on time overhead |
| Karri er al., | GANomaly and CNN algorithms | Reduced the computational complexity | However, fails to reduce time overhead |
| Wand et al., (2022) | Stacked Contractive Autoencoder and Support Vector Machines (SVM) | Reduced the analytical overhead | Not suitable for real time environment |
| Elsayed et al., (2022) | Graph Convolution Networks (GCNs) | Timely detection and prediction of security breaches | It does not predict and classify anomalies under change in the system behaviour |
| Nguyen et al.,(2021) | Mobile edge-cloud computation offloading system | Minimized the long-term system costs of latency, energy consumption | Performance gets degraded when the data is increased |
| Kimmel et al., | LSTM and Bidirectional RNNs (BIDIs) | Achieves high detection rates | Does not handle heterogeneous data |

| Loukas et al., (2018) | MLP and RNN | Reduction in detection latency | Increased communication overhead |
|---|---|---|---|
| Gard et al., (2019) | Grey wolf Optimization (GWO) and (CNN) | High accuracy and high detection rate | Increased computational complexity |

## III.    PROPOSED ARCHITECTURE

According to Fig. 1, the hybrid suggested network's framework is made up of three sub modules. In the first module, multiple datasets are pre-processed and inputted to the proposed network. The second module consists of the proposed SA-GRU-FF framework in which attention layer is integrated to remove redundant and non-optimal temporal features. These features are then fed into the fully connected deep feed forward networks based on Extreme Learning Machines (ELM) for classification of the multiple attacks.
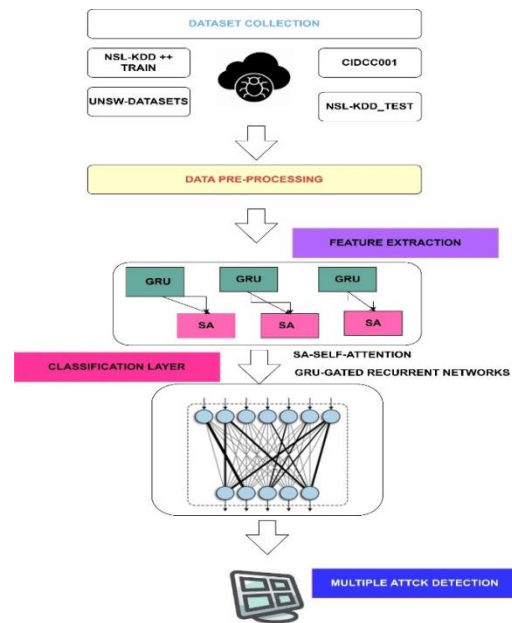


Fig. 1.    Proposed architecture for the GRU-SA-FF based multiple classifications of attacks.

### A.  Materials and Methods

Three distinct datasets, namely CIDDS-001 [27], UNSW-NB15 [28], and NSLKDD [29], are employed in this investigation. We choose the CIDDS-001 and UNSW-NB15 datasets because they are the most current statistics produced and include real data traffic, which makes them beneficial for designing accurate IDSs for tracking and finding novel forms of denial of service attacks in cloud networks. An IDS based on anomalies may now be created with the help of the CIDDS-001 dataset, which was just made accessible. In all, the collection contains around 32 million tracks, covering both normal and attack traffic. This dataset is composed of 12 identifying features and two distinguishing traits. Random sampling is applied to acquire 80,000 normal and 20,000 DoS attack events from the relational database of server traffic data, totaling 100,000 events. Using the extracted sample, the cross-fold validity and hold-out of the classifiers are tested. A new contribution to the public domain, the UNSW-NB15 dataset,

was also utilized for the purposes of testing. In the dataset, there are 49 characteristics and 1 class attribute. A subset of the dataset uses the training and test establishes, "UNSW NB15 Train & UNSW NB15 Test". There are 175,341 occurrences in the train set compared to 82,332 in the test set. "There are 56,000 occurrences of ordinary traffic and 119,341 illustrations of attack traffic on the platform set. Additionally, there are 37,000 examples of ordinary traffic and 45,332 cases of attack traffic in the test set". Hold-out confirmation makes use of both the whole train set and the test set, while cross-fold assessment solely utilizes the set that has been tested. The NSL-KDD dataset is then utilized to do classifier validation as well. 41 measures including 1 class attribute are part of the dataset. The NSL KDD dataset's KDDTrain+ (training) as well as KDDTest+ (testing) sets are utilised in this study. 13,499 attack traffic instances and 11,743 regular traffic instances make up the total 25,192 instances in the KDDTrain+ set. While the KDDTest+ set has a total of 22,544 instances, including 12,833 instances of regular traffic and 9,711 incidents of attack traffic. On each dataset separately, hold out as well as cross fold validation of classifers are performed. The selection of these sets was made to prevent randomly selecting cases from the entire NSL-KDD dataset.

### B. Data Reorganizing

The input data are first analysed, and then they are fed into a standardization approach, which assists to convert the bulk of attributes with numerical data to a specified numeric domain. Min-Max normalisation is used in conjunction with the linear transformation concept to accomplish this. After pre-processing step, new pre-processed datasets is formed from the original raw datasets. These pre-processed data is given for feature extraction module.

### C. Feature Extraction using Self –Attention Gated Recurrent Networks

The operation of gated recurrent sections, self-attention, and mixed combinations of self-attention gated recurrent units are covered in this section.

*1) Gated recurrent units – An overview*: One of most interesting form of LSTM is known as GRU the architecture is depicted in Fig. 2. The forget gate with input vector are intended to be combined into a single vector according to the concept set out by Chung et al. [30]. Both long-term sequences and memories are supported by this network. When contrasted to the LSTM network, the complexity is drastically reduced.
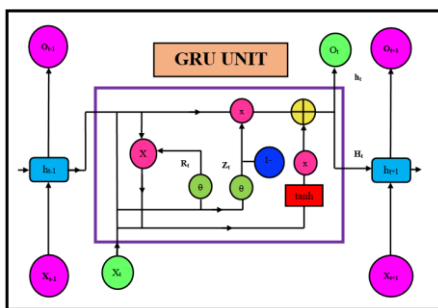


Fig. 2. GRU's architecture.

Chung developed the following equations to illustrate the traits of GRU.

$$h_t = (1 - x_t) \odot h_{t-1} + x_t \odot h_t \quad (1)$$

$$\tilde{h}_t = g(W_h x_t + U_h(r_t \odot h_{t-1}) + b_h \quad (2)$$

$$z_t = \sigma(W_h x_t + U_z h_{t-1} + b_z) \quad (3)$$

$$r_t = \sigma(W_h x_t + U_r h_{t-1} + b_r) \quad (4)$$

The following is the general GRU characteristic equation:

$$R = GRU(\sum_{t=1}^{n}[x_t, h_t, z_t, r_t(W(t), B(t), \eta(tannh))] \quad (5)$$

where, "xt ⇨input feature at the present state, yt ⇨output state , ht ⇨ output of the unit as of this moment, Zt & rt⇨update & reset gates, W(t) ⇨ weights, B(t) ⇨ bias weights at present instant".

*2) Self-awareness maps:* In 2014, the attentive map was proposed to describe the appropriate words in a sequence-to-sequence structure. In the vast mainstream of contemporary works, redundant characteristics that support accurate categorization mechanisms are imitated using attention layers. The self-attention process, commonly alluded to as the intra-attention procedure, generates the three vectors Q, K, and V for each input pattern. Thus, the results sequences are created by transforming the input patterns from all of the layers. It is a technique that, in its simplest form, maps the query string to the set of key-pair collections using logarithmic dot processes. The mathematical formula that follows can be used to get the dot multiplying for self-attention.

$$F(K, Q) = ((K), Q^T))/(V_K)^{0.5} \quad (6)$$

### D. Proposed Feature Extraction

BiGRU networks, which combine forward and backward GRU, are built for gathering meaningful information from the many dataset streams. Eq. (9) delivers data on the precise properties of the BiGRU network. In order to classify data, the BiGRU network collects spatiotemporal characteristics that incorporate a variety of different pieces of data. Although the training time, which makes up the overhead in the classification layer, may be affected by the more varied information in these characteristics. Self-attention layers that are inserted among the BiGRU network and classification layer help to diminish the resulting classification cost. Eq. (6) is used to create the attention characteristics retrieved from the input features of the BiGRU network that are then given to the feed-forward level of classification via the softmax layer.

$$P(F) = GRU\left(\sum_{t=1}^{n}[x_t, h_t, z_t, r_t(W(t), B(t), \eta(tannh))]\right) \quad (7)$$

$$P(B) = GRU\left(\sum_{t=1}^{n}[x_t, h_t, z_t, r_t(W(t), B(t), \eta(tannh))]\right) \quad (8)$$

Combining the Eq. (7) and Eq. (8)

$$P(BiGRU) = P(F) + P(B) \quad (9)$$

The following information is related to integrated Self-Attention (SA) with BiGRU feature extraction.

$$Y = Softmax (P(BiGRU), F(K, Q)) \quad (10)$$

## E. Feed Forward Classification Layers

After receiving these attributes for the fully connected forward feed-forward network, the final classifying is carried out. Layers are entirely linked using the ELM principle. The principle of auto-tuning capacity underlies the operation of a particular class of neural network known as an ELM, which only uses one hidden unit. In regards to dependability, speed, and computational burden, ELM performed better than other learning models like "Support vector machines (SVM), Bayesian Classifier (BC), K-Nearest Neighbourhood (KNN), and even Random Forest".

There is just one hidden layer in this specific neural network; therefore it may not require to be modified. Compared to other learning algorithms like Random Forest and Support Vector Machines, ELM operates better, more quickly, and with lower computational cost. Small training error and improved approximation are the ELM's main benefits. ELM uses non-zero activation functions and weight biases that are automatically tuned. The ELM's intricate operating mechanism is covered in [26]. Following Attention maps, the ELM's input features maps are represented by:

$$X = F(Y) \qquad (11)$$

where, Y $\Rightarrow$ features from Self Attention BiGRU network ,

*The ELM's output function is represented by the symbol*

$$Y(n) = X(n)\beta = X(n)X^T(\frac{1}{C}XX^T)^{-1}O \qquad (12)$$

ELM's comprehensive training is provided by:

$$S = \alpha(\sum_{n=1}^{N}(Y(n), B(n), W(n)) \qquad (13)$$

Finally, the softmax activation layers are applied for the above feedforward layers to achieve the best accuracy.

## IV. EXPERIMENTATION DETAILS

The entire algorithm was designed on an Intel Workspace with a 3.2 GHz of frequency, I7 CPU (NVIDIA GPU) and a16GB of RAM. Utilizing Keras (Tensorflow) as the rear end, the suggested baseline infrastructure was created.

## A. Performance Metrics

Deep feed forward training networks that classify the necessary classifications into typical sensitive and malicious information as well as the suggested design are validated as part of the experiment. Metrics including "accuracy, sensitivity, selectivity, recall, and f1-score" are used to gauge the suggested design's effectiveness. The calculations for the metrics used to assess the suggested architecture are shown in Table II in their respective computation formulae. Additionally, Table III shows the experimental hyperparameters that were utilized to train the suggested network.

## B. Results and Discussion

The experimentation is carried out based on component structures with the same parameters as the proposed framework. In detail, the existing structures were one dimensional Long Short Term Memory [30], Gated Recurrent Units [31], Optimized LSTM [23], and BiGRU [32]. The technique was

validated and a comparison study was performed using four different datasets.

TABLE III. ALGEBRAIC EQUATIONS FOR THE CALCULATION OF PERFORMANCE METRICS

| SL. NO | Validation Metrics | Formulae |
|---|---|---|
| 01 | Accuracy ($A_{cc}$) | $\frac{TP + TN}{TP + TN + FP + FN}$ |
| 02 | Sensitivity or recall ($R_{ll}$) | $\frac{TP}{TP+FN}$x100 |
| 03 | Specificity ($S_{ty}$) | $\frac{TN}{TN + FP}$ |
| 04 | Precision ($P_{cn}$) | $\frac{TN}{TP + FP}$ |
| 05 | F1-Score ($F_{cr}$) | $\frac{Precision * Recall1}{Precision + Recall1}$ |

Where, "TP – True Positive Values, TN – True Negative Values, FP – False Positive and FN – False Negative"

TABLE IV. HYPER PARAMETERS USED IN THE NETWORK'S TRAINING

| SL. NO | Hyper-Parameters | Specifications |
|---|---|---|
| 1 | GRU cell count | 10 |
| 2 | Epochs count | 200 |
| 3 | Batch Size | 30 |
| 4 | Learning Rate | 0.001 |
| 5 | Momentum | 0.2 |
| 6 | Dropouts | 0.2 |

TABLE V. USING THE CIDCC-001 DATASETS, EFFICIENCY STATISTICS OF THE DISTINCT ALGORITHMS

| Algorithms | Validation Metrics | | | | |
|---|---|---|---|---|---|
| | $A_{cc}$ | $P_{cn}$ | $R_{ll}$ | $S_{ty}$ | $F_{cr}$ |
| LSTM | 0.89 | 0.85 | 0.834 | 0.190 | 0.84 |
| GRU | 0.91 | 0.86 | 0.856 | 0.1556 | 0.857 |
| Optimized-GRU | 0.92 | 0.89 | 0.887 | 0.1290 | 0.885 |
| Proposed Model | 0.98 | 0.97 | 0.966 | 0.11 | 0.975 |

TABLE VI. USING UNSW2019 DATASETS, MONITORING OF THE MULTIPLE ALGORITHMS

| Algorithms | Validation Metrics | | | | |
|---|---|---|---|---|---|
| | $A_{cc}$ | $P_{cn}$ | $R_{ll}$ | $S_{ty}$ | $F_{cr}$ |
| LSTM | 0.874 | 0.87 | 0.864 | 0.150 | 0.86 |
| GRU | 0.902 | 0.90 | 0.89 | 0.110 | 0.91 |
| Optimized-GRU | 0.910 | 0.91 | 0.90 | 0.100 | 0.92 |
| Proposed Model | 0.983 | 0.98 | 0.974 | 0.011 | 0.983 |

TABLE VII.    NSL-KDD+(TRAIN) DATASETS PERFORMANCE INDICATORS OF THE SEVERAL ALGORITHMS

| Algorithms | Validation Metrics | | | | |
|---|---|---|---|---|---|
| | $A_{cc}$ | $P_{cn}$ | $R_{ll}$ | $S_{ty}$ | $F_{cr}$ |
| LSTM | 0.88 | 0.875 | 0.834 | 0.190 | 0.84 |
| GRU | 0.92 | 0.90 | 0.856 | 0.1556 | 0.857 |
| Optimized-GRU | 0.93 | 0.92 | 0.887 | 0.1290 | 0.885 |
| Proposed Model | 0.988 | 0.98 | 0.974 | 0.001 | 0.980 |

TABLE VIII.    NSL-KDD+(TEST) DATASETS PERFORMANCE METRICS FOR THE DIFFERENT ALGORITHMS

| Algorithms | Validation Metrics | | | | |
|---|---|---|---|---|---|
| | $A_{cc}$ | $P_{cn}$ | $R_{ll}$ | $S_{ty}$ | $F_{cr}$ |
| LSTM | 0.88 | 0.875 | 0.834 | 0.190 | 0.84 |
| GRU | 0.92 | 0.90 | 0.856 | 0.1556 | 0.857 |
| Optimized-GRU | 0.93 | 0.92 | 0.887 | 0.1290 | 0.885 |
| Proposed Model | 0.988 | 0.98 | 0.974 | 0.001 | 0.980 |



(a)



(b)



(c)
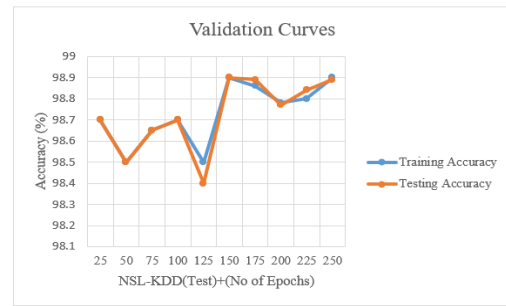


(d)

Fig. 3.    Validation performance of the suggested model using distinctive datasets a) CIDCC-001 datasets b) UNSW-datasets c) NSL-KDD datasets (Train) d) NSL-KDD datasets (Test).

Tables IV, V, VI, and VII demonstrates the proposed algorithm's performance metrics for categorizing several assaults using various datasets. The Table IV represents, the outcomes of proposed and existing frameworks when testing under CIDCC-001 Datasets. The Table V, Table VI and Table VI represents, the outcomes of proposed and existing model when testing under UNSW2019, NSL-KDD+(Train) and NSL-KDD+(TEST) datasets respectively. From Table IV, V, VI and VII, it is observed that, the suggested model GRU-SA-FF has demonstrated the best performance in detecting the numerous attacks. The integration of Self-attention maps has provided the best results in contrast to different DL techniques. Additionally, the validation effectiveness of the suggested model (see Fig. 3) is assessed using various datasets, and it is discovered that the RMSE (root mean square error) in between training and testing data is 0.001.
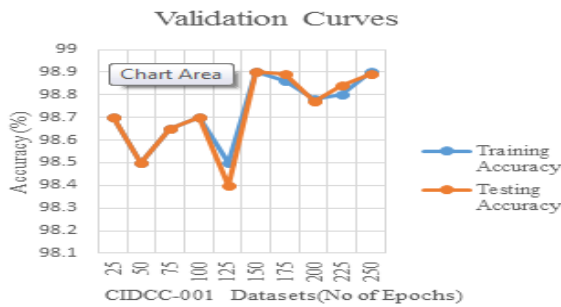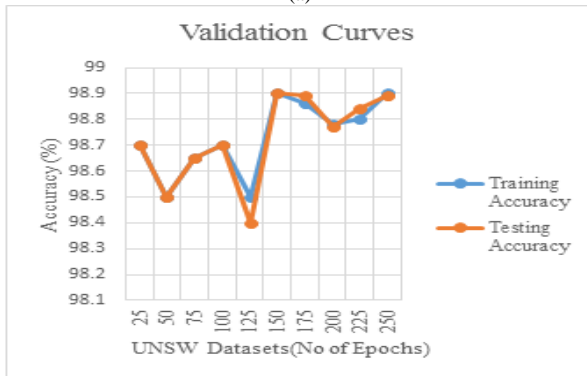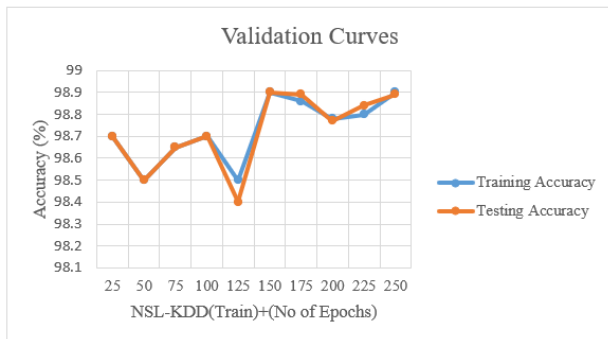
TABLE IX.    MBT IN SUPPORT OF DIFFERENT ALGORITHMS USING DIFFERENT DATASETS

| Datasets | (MBT)-secs | | | |
|---|---|---|---|---|
| | LSTM | GRU | Op-LSTM | Proposed Model |
| CIDCC001 | 0.5 | 0.45 | 0.37 | 0.23 |
| UNSW | 0.45 | 0.39 | 0.31 | 0.21 |
| NSL-KDD++ Train | 0.5 | 0.45 | 0.37 | 0.22 |
| NSL-KDD++ Test | 0.43 | 0.42 | 0.38 | 0.22 |

Model building times for various classifiers are shown in Table VIII for four datasets employing hold-out evaluation. Recognising how essential it is to deliberate how long a system needs train until it is successful at spotting various risks, the main driver aimed at estimating MBT is this realisation. Because of this, MBT helps to achieve a good trade-off among computational complexity and the accuracy of classifiers. The suggested model's average MBT when trained on the different sets of data is 0.22s, according to the above table, compared to 0.36s, 0.41s, and 0.48s for Op-LSTM, GRU, and LSTM, respectively, for Op-LSTM. According to the evaluation, the suggested framework uses only 0.22 seconds and excels at designing countermeasures against several threats.

V.    CONCLUSION AND FUTURE ENHANCEMENT

In this work, investigation on integration of Self-attention maps with GRU for securing the cloud against the multiple attacks is carried out. The role of self –attention network with the BiGRU to select the optimal features that can aid for the classification layers is proposed in this paper. Additionally,

role of feed forward layers which works on principle of ELM has been used in the proposed research to achieve the better classification with reduced computational burden and quick speed. Precision, specificity, susceptibility, false alarm rate, and region under the curve of receiver operating characteristics are used to assess the performance of the suggested model. On the CIDDS-001, UNSW-NB15, & NSL-KDD datasets, all of the classifiers are benchmarked. Results demonstrate in terms of a superior detection ratio and so little overhead, the proposed approach have done better over the other DL models. As the future scope, performance of the proposed model is required for the validation with real time datasets and also brighter light of deploying in the resource constraint in Cloud.

## REFERENCES

[1] Laghrissi, F., Douzi, S., Douzi, K. et al., "IDS-attention: an efficient algorithm for intrusion detection systems using attention mechanism." J Big Data, Vol 8, 149, 2021.

[2] Maha M, Althobaiti K, Mohan KP, Deepak G, Sachin K, Mansour RF. "An intelligent cognitive computing based intrusion detection for industrial cyber-physical systems." Measurement. 2021, 186(110145):0263–2241.

[3] Anthi E, Javed A, Rana O, Theodorakopoulos G "Secure data sharing and analysis in cloud-based energy management systems." In Cloud Infrastructures, Services, and IoT Systems for Smart Cities, pages 228–242. Springer, 2017

[4] Baykara, M., & Das, R. "A novel hybrid approach for detection of webbased attacks in intrusion detection systems." International Journal of Computer Networks and Applications, 4(2), 62–76, 2017

[5] Bergstra, J., &Bengio, Y. (2012). "Random search for hyper-parameter optimization." Journal of Machine Learning Research, 13(Feb), 281–305.

[6] Mahboob AS, Moghaddam MRO. "An Anomaly-based Intrusion Detection System Using Butterfy Optimization Algorithm," 6th Iranian Conference on Signal Processing and Intelligent Systems (ICSPIS), 2020; pp. 1-6

[7] BButun, I., Morgera, S. D., &Sankar, R.. "A survey of intrusion detection systems in wireless sensor networks." IEEE Communications Surveys & Tutorials, 16(1), 266–282, 2014

[8] Chen, T., &Guestrin, C. (2016). Xgboost: A scalable tree boosting system. In ACM, proceedings of the 22nd ACM SIGKDD international conference on knowledge discovery and data mining (pp. 785–794).

[9] Khan MA. HCRNNIDS: hybrid convolutional recurrent neural network-based network intrusion detection system. Processes. 2021; 9(5): 834.

[10] Shen Y, Zheng K, Wu C, Zhang M, Niu X, Yang Y. An ensemble method based on selection using bat algorithm for intrusion detection. Comput J. 2018;61(4):526–38.

[11] Demšar, J. (2016). Statistical comparisons of classifers over multiple data sets. Journal of Machine Learning Research, 7(Jan), 1–30.

[12] Dhanjani, N. (2013). Hacking lightbulbs: Security evaluation of the philips hue personal wireless lighting system. Retrieved November 3, 2019, from https://www.dhanjani.com/docs/Hacking

[13] Diro, A. A., &Chilamkurti, N. (2018). Distributed attack detection scheme using deep learning approach for Internet of Things. Future Generation Computer Systems, 82, 761–768.

[14] Girma A, Garuba M, Goel R. Advanced machine language approach to detect DDoS attack using DBSCAN clustering technology with entropy. In: Latifi S, ed. Information Technology - New Generations. Advances in Intelligent Systems and Computing, 2018, vol. 558. Cham, Switzerland: Springer, pp. 125–131

[15] Douglas, P. K., Harris, S., Yuille, A., & Cohen, M. S. (2011). Performance comparison of machine learning algorithms and number of independent components used in FMRI decoding of belief vs. disbelief. Neuroimage, 56(2), 544–553.

[16] P. Abirami, S. Vijay Bhanu and T. K. Thivakaran, "Crypto-Deep Reinforcement Learning Based Cloud Security for Trusted Communication," 2022 4th International Conference on Smart Systems and Inventive Technology (ICSSIT), 2022, pp. 1-10, doi: 10.1109/ICSSIT53264.2022.9716429.

[17] Y. Tao, J. Qiu and S. Lai, "A Hybrid Cloud and Edge Control Strategy for Demand Responses Using Deep Reinforcement Learning and Transfer Learning," in IEEE Transactions on Cloud Computing, vol. 10, no. 1, pp. 56-71, 1 Jan.-March 2022, doi: 10.1109/TCC.2021.3117580.

[18] S. Hizal, Ü. ÇAVUŞOĞLU and D. AKGÜN, "A new Deep Learning Based Intrusion Detection System for Cloud Security," 2021 3rd International Congress on Human-Computer Interaction, Optimization and Robotic Applications (HORA), 2021, pp. 1-4, doi: 10.1109/HORA52670.2021.9461285.

[19] C. Karri and M. S. R. Naidu, "Deep Learning Algorithms for Secure Robot Face Recognition in Cloud Environments," 2020 IEEE Intl Conf on Parallel & Distributed Processing with Applications, Big Data & Cloud Computing, Sustainable Computing & Communications, Social Computing & Networking (ISPA/BDCloud/SocialCom/SustainCom), 2020, pp. 1021-1028, doi: 10.1109/ISPA-BDCloud-SocialCom-SustainCom51426.2020.00154.

[20] W. Wang, X. Du, D. Shan, R. Qin and N. Wang, "Cloud Intrusion Detection Method Based on Stacked Contractive Auto-Encoder and Support Vector Machine," in IEEE Transactions on Cloud Computing, vol. 10, no. 3, pp. 1634-1646, 1 July-Sept. 2022, doi: 10.1109/TCC.2020.3001017.

[21] M. A. Elsayed and M. Zulkernine, "PredictDeep: Security Analytics as a Service for Anomaly Detection and Prediction," in IEEE Access, vol. 8, pp. 45184-45197, 2020, doi: 10.1109/CCESS.2020.2977325.

[22] D. C. Nguyen, P. N. Pathirana, M. Ding and A. Seneviratne, "Secure Computation Offloading in Blockchain Based IoT Networks With Deep Reinforcement Learning," in IEEE Transactions on Network Science and Engineering, vol. 8, no. 4, pp. 3192-3208, 1 Oct.-Dec. 2021, doi: 10.1109/TNSE.2021.3106956.

[23] J. C. Kimmel, A. D. Mcdole, M. Abdelsalam, M. Gupta and R. Sandhu, "Recurrent Neural Networks Based Online Behavioural Malware Detection Techniques for Cloud Infrastructure," in IEEE Access, vol. 9, pp. 68066-68080, 2021, doi: 10.1109/ACCESS.2021.3077498.

[24] G. Loukas, T. Vuong, R. Heartfield, G. Sakellari, Y. Yoon and D. Gan, "Cloud-Based Cyber-Physical Intrusion Detection for Vehicles Using Deep Learning," in IEEE Access, vol. 6, pp. 3491-3508, 2018, doi: 10.1109/ACCESS.2017.2782159.

[25] S. Garg, K. Kaur, N. Kumar, G. Kaddoum, A. Y. Zomaya and R. Ranjan, "A Hybrid Deep Learning-Based Model for Anomaly Detection in Cloud Datacenter Networks," in IEEE Transactions on Network and Service Management, vol. 16, no. 3, pp. 924-935, Sept. 2019, doi: 10.1109/TNSM.2019.2927886.

[26] Verma, A., &Ranga, V. (2018). Statistical analysis of CIDDS-001 dataset for network intrusion detection systems using distance-based machine learning. Procedia Computer Science, 125, 709–716.

[27] Verma, A., &Ranga, V. (2019a). ELNIDS: Ensemble learning based network intrusion detection system for RPL based Internet of Things. In 2019 4th International conference on Internet of Things: Smart innovation and usages (IoT-SIU) (pp. 1–6). IEEE.

[28] Verma, A., &Ranga, V. (2019). Evaluation of network intrusion detection systems for RPL based 6LoWPAN networks in IoT. Wireless Personal Communications, 108(3), 1571–1594.

[29] J. Chung, C. Gulcehre, K. Cho, and Y. Bengio, "Empirical evaluation of gated recurrent neural networks on sequence modeling," arXiv preprint arXiv:1412.3555, 2014

[30] Staudemeyer RC. 1 Applying long short-term memory recurrent neural networks to intrusion detection. South AfrComput J. 2015;56(1):136–54.

[31] Kim J, Kim J, Thu HLT, and Kim H. Long short term memory recurrent neural network classifer for intrusion detection, In Proc. Int. Conf. Platform Technol. Service (PlatCon); 2016, pp. 1–5.

[32] Shen Y, Zheng K, Wu C, Zhang M, Niu X, Yang Y. An ensemble method based on selection using bat algorithm for intrusion detection. Comput J. 2018;61(4):526

# An Efficient Method for Implementing Applications of Smart Devices Based on Mobile Fog Processing in a Secure Environment

Huaibao Ding, Xiaomei Ding*, Fang Xia, Fei Zhou

School of Computer Engineering, Anhui Wenda University of Information Engineering, Hefei 231201, China

*Abstract*—Smart technology and the Internet of Things (IoT) are advancing and growing daily in the modern world. The demand for solutions to execute complex applications and protect user security and privacy increases as the number of smart devices in our surroundings increases. Mobile fog processing aids us in this situation by providing a fresh and effective method for running smart device applications in a safe setting. Due to the delay and high volume of requests, the centralized and traditional architecture of cloud processing cannot handle the high user demand and effectively implement delay-sensitive and real-time programs. To address these issues, a virtual mobile fog processing architecture that establishes a layer between mobile apps and the cloud layer was developed in this work. In this layer, storage, processing, and encrypted communication occur on separate nodes not connected to the cloud. These nodes are virtually implemented on a single server. An Android smart system-based augmented reality application that uses a marker to display dynamic 3D objects has been introduced. Its functioning has been assessed in both the cloud-based architecture and the suggested architecture in two 4G and telecom mobile internet networks. The evaluation findings demonstrate the suggested architecture's superior performance in both communication networks. The suggested mobile fog-based architecture makes use of the Internet of Telecommunications to create high-volume 3D models quickly and to the satisfaction of a real-time application. In addition to these accomplishments, the results demonstrate that the suggested architecture outperforms typical cloud-based architecture in terms of lowering overall energy consumption by up to 34%.

*Keywords—Cloud environment; IoT; real-time systems; smart devices; mobile fog; energy consumption*

## I. INTRODUCTION

The administration of networks, storage, and computation has all faced numerous difficulties with the growth of the mobile Internet and the IoT [1]. High latency, a lack of storage space, scarce resources, round-the-clock services, and security are problems that can't be accurately solved with a cloud computing architecture [2]. A computer is a subset of computer resources, such as servers, storage, and processing space, used to centrally collect and process data from many clients at once [3]. These resources are accessible via customary means and are active in the network [4]. Network delays are caused by the allocation of resources among end users and clouds due to resource concentration in cloud spaces. Solving these issues is crucial for a number of delay-sensitive applications, including transport networks and augmented reality [5].

For this reason, the processing power in various Internet of Things networks has recently increased with the development of cloud and fog computing, and by shifting a portion of the processes to data centers in the fog, the amount of delay and limitations of the Internet of Things have been reduced and improved [6]. Mobile edge computing (MEC) and mobile cloud computing (MCC) are new technologies that have arisen as a result of the substantial role that smart mobile devices play in the expansive realm of the Internet of Things [7]. The use of cloud computing capabilities at the network's edge is a trait shared by all of these systems. When IBM and Siemens' Nokia Networks created an infrastructure that could run applications on a mobile base station in 1923, the term mobile edge computing was first used to describe the implementation of services at the network's edge [8].

European Telecommunications Standards Institute (ETSI) has created reference architecture since 2016 whose functional components support services like program execution at the radio network's edge [9]. Edge computing was developed to address issues with reaction speed, limited battery life, reduced bandwidth costs, and data security and privacy [10]. Additionally, processing and storage facilities at the edge can work together or independently. The control approach in the MEC design is dispersed hierarchically and centrally, in contrast to the centralized control of resources in the MCC [11]. Cloud computing (FC), a different horizontal architecture that distributes resources and services and offers computing, storage, and network control prior to reaching the cloud, was introduced at the system level for networks. When used with mobile devices, cloud computing technology offers quicker and higher-quality services [12]. In order to connect smart devices and provide services in a virtual form (VMFC), mobile processing can be used. All processing and operational services can be accessed through these virtual machines or a network of virtual machines [13]. In addition to providing MEC services, virtualization infrastructure can offer other related services, like the virtualization of software-defined network operations [14]. This article aims to offer a VMFC-based approach that can be utilized to construct a fog layer employing virtual nodes before the cloud layer. This layer's use for applications in smart devices, which have a dedicated node for each network of smart devices, including those for gaming, education, and health, is its unique feature. The author's contribution to this work can be summed up as follows:

- A virtual mobile fog processing architecture is offered to meet the increased user demand and ensure that real-time and delay-sensitive applications are run correctly.

- Two 4G mobile internet and telecommunication networks have been assessed for a pointer-based augmented reality application with dynamic 3D object presentation on Android smart systems.

The various sections of the article are further explained in the sections that follow: In Section II, a summary of the work completed in the MEC, MCC, and FC contexts is provided, and the benefits and drawbacks of each are compared to the proposed work. The suggested methods are provided in Section III. In Section IV, we demonstrate how this strategy is used using an example from an augmented reality application. In Section V, we discuss the suggested method and analyze the outcomes. A summary of this study's findings is provided in Section VI.

## II. RELATED WORKS

Mobile phone networks make up a sizable portion of the Internet of Things. Because of their great computational capacity, they need to develop a second network layer to minimize the processing burden on the devices, reduce delay, and conserve bandwidth and energy when connected. The distant cloud server is displayed. Applications for active mobile phones in the Internet of Things networks, such as monitoring stations and smart houses, traffic data transfer, health data transmission in medical networks, augmented reality programs, large data processing in smart cities, and learning through mobile devices The mobile phone and the games utilize less computing and processing power and have shorter battery lives since the computing and processing load is offloaded to the cloud layer. The term "augmented reality" refers to a live physical perspective that instantaneously adds components to the real world of people, either directly or indirectly, and typically in contact with the user [15]. Programs for augmented reality that run on mobile devices need. The proper presentation of information requires high-speed data processing and minimal delay [16]. Cisco first developed cloud computing in 2022 [17], which is an expansion of the cloud computing platform that provides processing, storage, and network services between end devices and traditional cloud servers. In addition to network virtualization and traffic engineering via network performance virtualization, the researchers defined an architecture that supports some edge technologies, including ZigBee, Bluetooth, LoRa, and Wi-Fi [18]. Other investigations have been into edge processing's interoperability with the Internet of Things software. Fog nodes were created in this study as edge devices for various machine-to-machine services and machine-to-machine device management systems, such as road processing units in-vehicle networks. This approach did not take into account other factors like application migration or compatibility and was only effective for a small number of locations. This interpretation states that MEC offers a technological environment with cloud computing capabilities at the mobile network's edge. Utilizing cloud services at the edge of a network of smart devices has several benefits, including low latency, high bandwidth, access to radio network information, and local awareness. An edge

scheduler that reduces the device's typical traffic delay is an example. It was demonstrated that the average energy cost in fog computing is 40.48% less than the model in a quantitative examination of energy consumption in a scenario where 25% of Internet of Things applications require real-time services and low latency [19]. Processing in the cloud is usual. In one study, they used the cloud and cloud computing to boost the processing capability of a network of wireless sensors for military applications and real-time execution to get around program limits and damage. A different work sample has offered a collection of applications that enable virtual machines to connect to cloud nodes and offer services. These applications enable virtual computers to access regional data, including sensor data, network statistics, etc. In a project, multiple researchers produced numerous copies of portable programs and several smart gadgets in the cloud [20]. They were moved from the machine to the duplicate. Consequently, a virtual copy of the gadget exists in case the actual one is destroyed or lost. This method also has the benefit of addressing the hardware constraints of smart devices. In a project, they demonstrated the viability of combining the 5G network platform with MEC and the accessibility of underused indoor and external spaces. Another project in the area of big data analysis utilized the convergence of MCC and Hadoop. The traffic congestion and time delay for their task were not resolved by paying attention to the amount of processing data in this strategy. Another piece of work on the subject of smart health involved gathering sensor data and sending it to a mobile device so that it could be processed and used to generate an alarm in an emergency [21]. None of the MCC or MFC services were used in this work. In one project, a mobile cloud server was used to develop an intelligent communication architecture for unmanned air transport networks. Their suggested design may maintain communication over a long period of time, even in the event of network failure, by improving network dependability and stability. Additionally, it can defeat DDoS, Sybil, and Wormhole attacks. In the MEC environment, a location-based augmented reality program has been built. Based on the tracking and identification of the user's position on the edge of an object, it is loaded. Utilizing this architecture significantly reduced mobile phones' computational load and energy usage [22]. Through the use of augmented reality technology, a different program on the topic of digital education was put into place. An image was recognized and exhibited in its static, three-dimensional surroundings. A cloud server was employed in this program to lessen the computational load and energy usage. The more straightforward steps of diagnostics were carried out on the mobile phone, while the more complex programs were moved to the cloud [23]. The program for augmented reality now loads frames more quickly, thanks to the evaluation of this effort. In another application dealing with augmented reality based on cloud processing, a photo of the book columns was taken, the features extracted, and sent to the cloud on the mobile phone [24]. Then, using the information obtained, a search was conducted among the database records in the cloud environment. Information about comparable works is gathered and sent back. In the studies and the use of cloud processing reduced the computational workload and energy consumption of the mobile phone, but the issue of high cloud latency and its

distance from availability limited the use of MCC architecture for delay-sensitive applications [25-27]. It was immediately noted that this delay increased the mobile phone's energy use.

The delay issue has been largely resolved in [28], but if base station traffic volume rises, we will need to impose traffic limitations. The study proposed a successful approach to shorten the transfer time from users to distant clouds by utilizing the edge environment [29-30]. In this work, data and objects were entirely moved to the edge environment in order to conserve memory and processing in an electronic learning program based on augmented reality. The effectiveness of the study that was given demonstrated how the suggested strategy could significantly enhance memory storage performance. Edge nodes were created as road units in-vehicle networks in [31] to provide IoT services using OpenM2M in order to reduce network delay and traffic. For the purpose of reducing the typical scheduling and delay time, the authors of [32] investigated the multi-user computing partitioning problem (MCPP). To overcome the issue in delay-sensitive applications, they employed an offline exploratory technique called search in the model (SAPRL). Because of the work done in the MEC environment, all augmented reality applications based on 2D images, 3D edge detection, and sensor detection can be implemented. It is more suited for location-based augmented reality programs and is not extensively employed in health, education, or architecture networks. Due to the limited ability of control units and operator base stations to locate mobile phone devices, this feature is possible. Fog computing is actually a way of processing data from its point of generation to its point of storage. Only processing data close to its original location is attributed to edge computing. In addition to edge computing, fog computing refers to the network connections required to transport data from the edge to its terminus [33]. The use of mobile computing, particularly in mobile and network environments, offers users several advantages while lowering program running costs and conserving computer resources. In general, as mobile phone base stations improve and information technology and telecommunications networks converge, the use of mobile computing is a logical progression. Edge computing, where part of the data processing takes place at the network's edge rather than wholly in the cloud, was made possible by the Internet of Things' congestion and the constraints of cloud services. The problems of latency, mobile device battery life, bandwidth costs, security, and privacy can be resolved via edge computing. The comparison of the three described architectures is shown in Table I. The activities that have been completed have made use of MCC architecture to improve services for mobile devices, which are limited in their ability to run delay-sensitive programs due to the high delay of the cloud layer and the difficulty in accessing it. The fog support service has not been employed in many projects that have been simulated on smart devices. Some of the issues with MCC architecture, such as slowness, have been resolved through the use of MEC architecture. However, there is an issue of delay in the event of crowding when one is in an area of service stations because of the use of a high number of mobile phone devices. The inability to easily access the servers of mobile phone network carriers is another issue with deploying MEC. Applications cannot be uploaded to operators' servers without special authorization. One of our aims in writing this post is to offer programmers and consumers an approach that is simple to use and affordable. As part of the ongoing study, we will show an approach based on MEC and fog processing that is simple to use, and based on this architecture, we will use augmented reality technology to create a portion of a delay-sensitive application. The VMFC approach facilitates the study of local data by building a hierarchical infrastructure and moving global coordination and analysis to the cloud.

TABLE I.    COMPARISON OF MCC, MEC, AND VMFC ARCHITECTURES IN TERMS OF FEATURES

| Specification | MCC | MEC | VMFC |
|---|---|---|---|
| Expandability | high | Medium and limited | high |
| location | A higher level than the devices and out of reach | The edge of mobile devices | Between devices and the cloud |
| Hierarchical architecture | Two levels | Three levels | More than three levels |
| Server Hardware | Very large data centers | Small data centers | Small data centers |
| Control systems | Central | Distributed centralized hierarchy | Non-distributed hierarchy |
| amount of delay | high | medium | Low |
| They use it | Lots of devices and networks | The average number of devices and networks | The average number of devices and networks |
| How to connect | All internet networks | Base stations and operators | All internet networks |
| Interaction and cooperation between nodes | Does not exist | Does not exist | There is |
| Energy consumed by devices | medium | Low | Low |
| Implementation cost | medium | medium | low (virtualization capability) |
| User access | In a remote place and in case of heavy traffic, it isn't easy to access | Close and easy with the condition of being in the service area and having a service | Close and easy access |
| Access to programmers to develop all kinds of programs | Almost as easy with registration or fees | Easy if you have a license to access the servers located in the license base station | Easy with registration |
| Implementation of a delay-sensitive application such as augmented reality | Reduced computational load - high latency | Lack of support for the implementation of various augmented reality programs in case of medium delay congestion | Very low latency suitable for most augmented reality applications |

## III. PROBLEM IDENTIFICATION AND SUGGESTED SOLUTION

The problem's definition and the suggested model are covered in this section. You can upload computational jobs to the fog layer or run them locally on the device. The speed of the processing process can be greatly increased by uploading processing tasks to be completed at the network's edge. Fog nodes execute applications alongside centralized cloud servers, but they are not required to run for services since fog nodes can process applications independently and reply to users. Between the application and the cloud layer, this layer serves as a backup. The internal organization of this layer is utilized to speed up user access to the services they need. ETSI has provided the web foundation for MEC servers, templates, and software. We proposed a hierarchical architecture based on MFC in this article by researching and analyzing this architecture, as seen in Fig. 1. This design uses active networks of smart devices to deliver specific services to networks that are connected to it as well as the larger Internet of Things. The administration of network connectivity, processing, speed, storage, and control are a few examples of tasks that can be carried out at each fog node in this architecture. At a higher level, each mobile network is connected to a set that comprises one or more fog nodes. Nodes can communicate with one another wirelessly or over connected connections.

There are two options for loading programs in the cloud node: loading the complete executable program or just a portion of it. Depending on the application, each VMFC layer of the MFC layer is made up of a number of nodes. Nodes are interconnected for application management, data processing, storage, and security services. Each node is in charge of offering the designated services at both the level of that node and a higher level. Each VMFC layer collaborates with its neighboring layers as necessary. In the MCC layer, big data collection takes place at a higher level. This layer is in charge of overseeing and supporting MFC, which is a lower-level layer. Additionally, this layer is in charge of documenting, confirming, and securing access for VMFC nodes to connect with one another as needed. This layer houses data centers and big data storage.

The MFC layer and the MCC layer communicate with each other over the Internet. Active technologies like WLAN, ZigBee, 4G LoRa, and 5G are used to connect applications on smart devices to the cloud layer so they can receive service and storage in a secure environment. Frameworks like: NET and Java are frequently used to create applications since they make the process of transferring code easier.
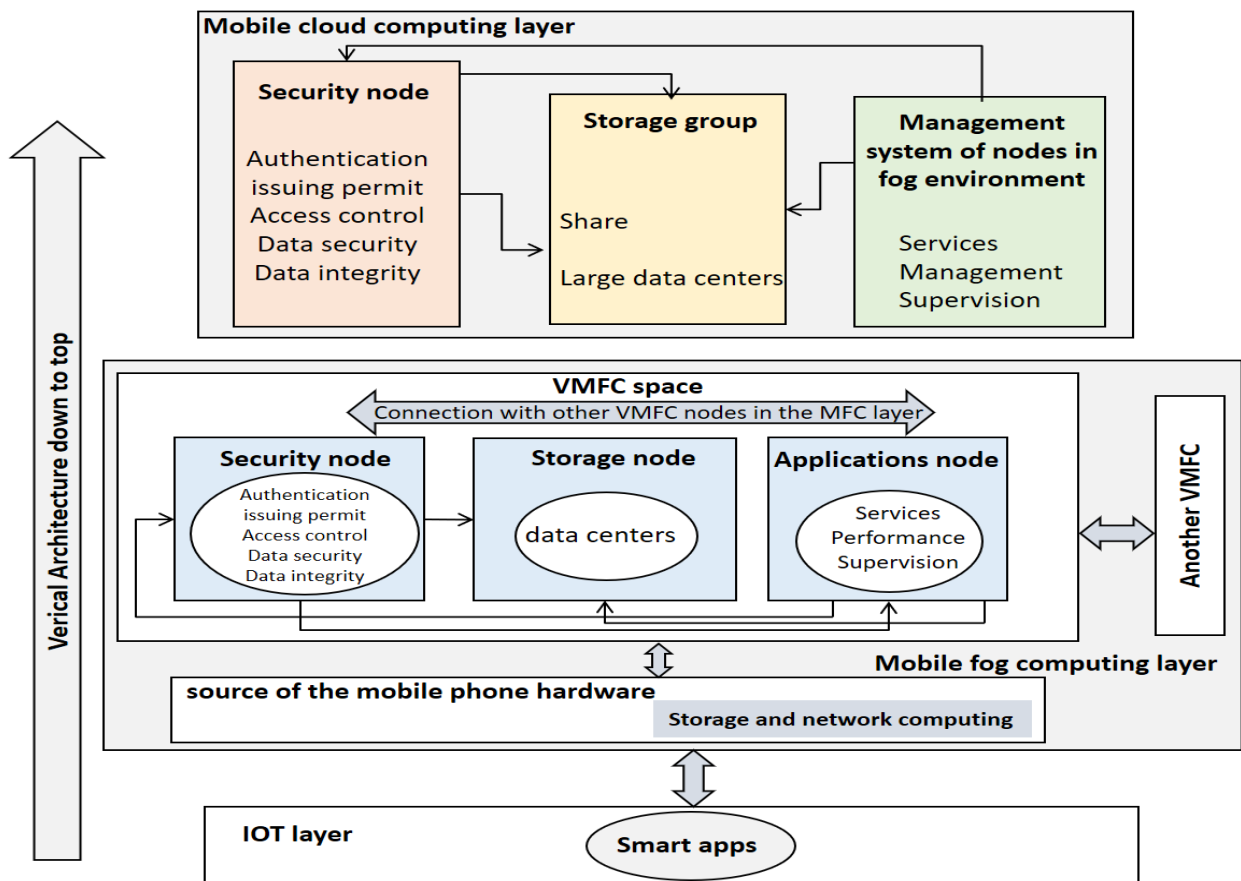


Fig. 1. Block diagram of the proposed model.

## IV. IMPLEMENTATION OF THE ARCHITECTURE

This section explains how to put the suggested method into practice. In this system, two fog nodes were employed for program execution, processing, and authentication. The fog layer is made up of two distinct nodes: one is used for security, and the other is used to store and process the application program. The two nodes here are linked. These two nodes are implemented and set up using two virtual computers. The data storage node is not taken into account independently [34]. Every node used for processing has a database for storing the sent and necessary data related to other data. The Java framework has been used to implement the application program. Fig. 2 demonstrates how to use two nodes for the application and security to create the application based on the suggested way described in Section III. Each node contains the node database, which is not a separate entity. On the needed server, each user registers their information and builds a profile. The executable application responds to the user's request for some space. The user is allotted a specific amount of space for each component of their profile, which is separated into many sections. An individual identification number is assigned at random to each segment [35]. The address of the user's profile and the ID of each section written in a piece of code is used to direct the program in order to log in and run the program uploaded in the virtual space. The security node receives the data entered in the processing and storage node and enters it into the profile for registration and verification. The initial step in accessing the cloud server to carry out processing is user authentication. A software ID is generated for the user when they register their information.

Each piece of software is identified by a special key called software ID. With this special key, all requests are signed, and it is also used to verify signatures. The procedure for getting the token in a mobile edge scenario is the same as this one.

The authentication header bears the signature. The time tag and request identification features in this header guard against broadcast and propagation attacks. The signature also changes if the person's ID changes [36]. In order to verify and register the user's codes in his profile database, this signature must be written in a section of the application's Android code that is utilized while loading program data and performing the necessary cloud-based operations. Using a browser to connect to the Internet, the user can access his profile and read and update his data from any location. The application uses an image-based augmented reality program to run dynamic 3D objects. Each 3D object depends on a pointer, which means that it can only be seen by scanning the pointer. The second fog node is utilized in this architecture to store and process the pictures needed to execute the augmented reality software. The outcome of the image processing is then compared to the user's pointer, and the appropriate three-dimensional image is presented. Everywhere the user's marker is, a 3D image of it can be seen. Visual indicators are the type of indicators employed in this project. Between ID-based markers and markerless technology, there is an image marker. With this technique, any image can be used as a target by being printed out; the target should be a colored border against a light background. The image's border need not be black; it might be a dark hue.
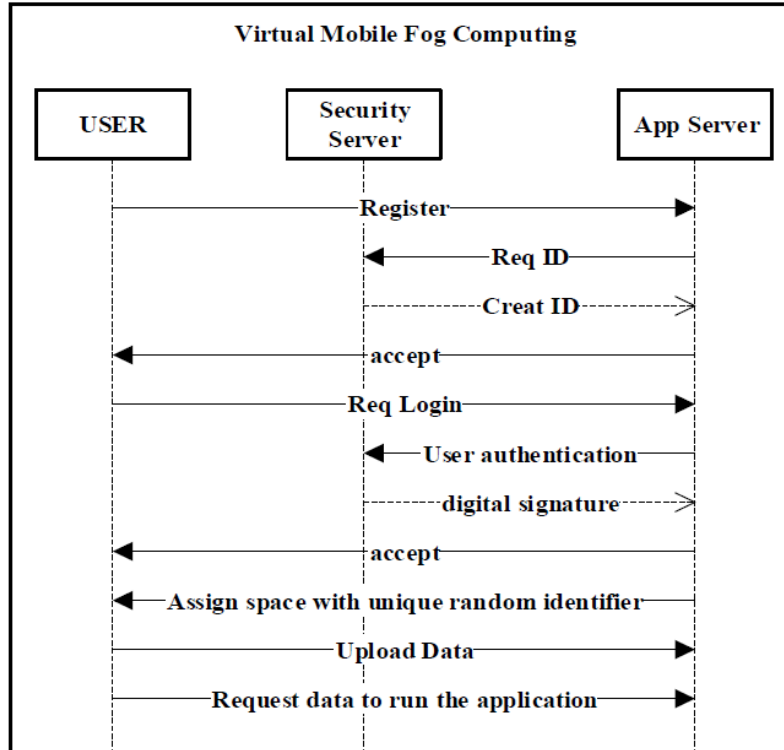


Fig. 2.   Data recording and transfer flow in the proposed method.

Developers can use images and track them in pointer-based programs, depending on the requirements of the program. A low-poly model is a low-poly model, and a high-resolution model is a high-poly model. These classifications are based on the tool and how the models are applied. Models of lower resolution, or low-poly models, are frequently employed in real-time systems to boost program efficiency and speed up execution. In a 3D model, a polygon is defined by a number of other polygons. This unit is typically represented by a collection of triangles. The quantity of triangles produced on the 3D model determines how clear the implemented models are. The application node processes a portion of the software in such a way that the user can load a sample of the marker in addition to the desired 3D model. According to each marker with a 3D object and its properties, the.xml file is saved and loaded. The marker that identifies the mobile phone camera and its application is delivered to the fog node each time, the program is run and is compared to the markers in the processing node. If they match, the matching 3D model is presented. When matching and running, 3D models are merely loaded and presented from the node and are not saved on the mobile device. An.xml file with the 3D object's properties is loaded into the user's profile.

## V. DISCUSSION

In this section, we describe the assessment of the developed technique in two scenarios: local execution while using the suggested VMFC approaches and using a mobile phone. According to the volume difference, we look at two frame execution rate parameters in each 3D model, and then we compare how long it takes to load data from VMFC and a ready cloud service. To upload data, we took advantage of the Junaio cloud storage service. With the help of the augmented reality browser Junaio, users may build and use augmented reality programs on a variety of platforms [37]. You must first create a channel in this browser in order to upload the augmented reality programs you have generated and assigned to each channel. Dynamic 3D models have restrictions on mobile phones since they require a lot of processing speed to operate and a lot of storage space as the number and volume of data increase. These models, which can move and animate, are made up of a number of layers, each of which mimics a movement. A frame or polygon is the name given to each of these layers. To show a specific movement that has been applied to the object, it is imperative to execute these polygons one after the other. On the other hand, augmented reality programs are real-time programs, and one of the crucial aspects in this sector is the quick execution rate of an event. Six 3D objects with extensions.FBX,.md2,.mm3d, and.ms3d are utilized in this software, ranging in size from 180 to 450 KB. As was already noted, the number of created polygons and the speed at which they are executed determine the resolution of models. In this case, triangles, each 80KB, comprise around 10,000 polygons. A bandwidth of 29 MB/s is required to implement this flow. In frames per second, 3D models are executed. This unit specifies the vertex of the polygons transferred from memory to the screen. If a program loads less than 20 frames per second while running, it indicates that the program is not operating smoothly and rapidly. It is reasonable for programs to transfer at least 20 frames per second while

running. Depending on the size of the model, the mobile phone uses a specific amount of device energy to load each of the models and transport them on the screen. Data is loaded into the ES FileExplorer environment and then transferred for presentation to the main program. Eq. (1) is used to compare the difference in program execution time between VMFC and cloud services:

$$T = \frac{R}{S} \times (T_r + T_h + T_s) \quad (1)$$

where, R is the anticipated request ratio, S is the total number of requests that the machine can handle concurrently, $T_r$ is the amount of time it takes for data to travel from the user's mobile device to the virtual machine, $T_h$ is the amount of time it takes for the virtual machine to respond to the request, and $T_s$ is the amount of time it takes for data to travel from the virtual machine to the user's mobile device. We assumed the value for both services to be the same and constant in this R equation. The amount of data being transferred and the network conditions—which are typically poor for mobile networks when handling heavy data loads—determine how long it will take to complete. The user response waiting period has been left out of this calculation because it is not crucial to resource allocation. Six different data sets with varying volumes were examined using the program's implementation on two separate platforms, including WLAN and 4G mobile internet. The software was implemented in three parts based on a cloud server, mobile device, and VMFC and the evaluation metrics were looked into and examined. Internet telephony was utilized to compare the frame transfer rate of 3D models in VMFC. In Fig. 3, the speed and quantity of transitions of the 3D model polygons corresponding to the marker in the minimal normal state are displayed after the mobile phone camera recognizes and processes a marker. For the 3D models incorporated into the program, this value is computed. Fig. 4 illustrates the frame transmission rate to the screen from the mobile phone and the VMFC in contrast to the minimum normal speed. The application takes into account a certain number of polygons for processing on the model and transfers them for display based on the volume of the models being utilized. The 3D model and its dynamic movements must be executed and displayed at a minimum speed of 20 frames per second. For low-volume models, the transfer speed of the frames processed in the application in the mode where the model is loaded from the mobile phone memory is acceptable, and it almost exactly matches the transfer speed from the VMFC to the mobile phone's temporary memory. However, compared to a mobile phone, the transfer speed from a VMFC is faster and offers greater performance when the model volume and count are both raised.

The FBX model has a larger volume than other models, and its memory consumption is also higher. The speed of frame transfer in this model and larger model is higher than loading in a mobile phone. Loading 3D models in VMFC in this program has saved about 1 gigabyte in mobile phone memory. Data transfer from the mobile phone to the Ebro VMFC server was checked in two Internet communication networks. The present research compares the transmission speed values frames in mobile application execution and transmission speed after using VMFC. Paired t-analysis was used after and before

using VMFC to determine if there was a change in the transmission speed of frames.

Table II shows the details of this statistical survey. As can be seen in Table II, the rate of frame transfer before using

VMFC was 84.250, and after using VMFC, it increased to 83.333, and this increase was statistically significant (p=0 /032) is significant.
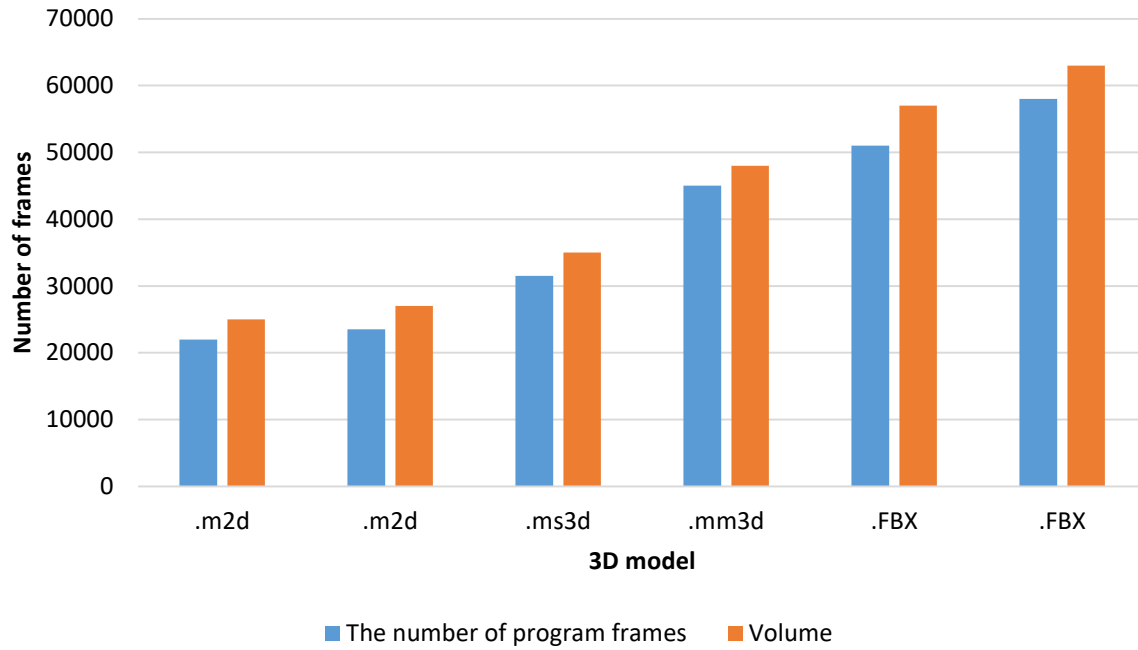


Fig. 3.    Volume and number of frames and normal speed of loading seven objects in the program.
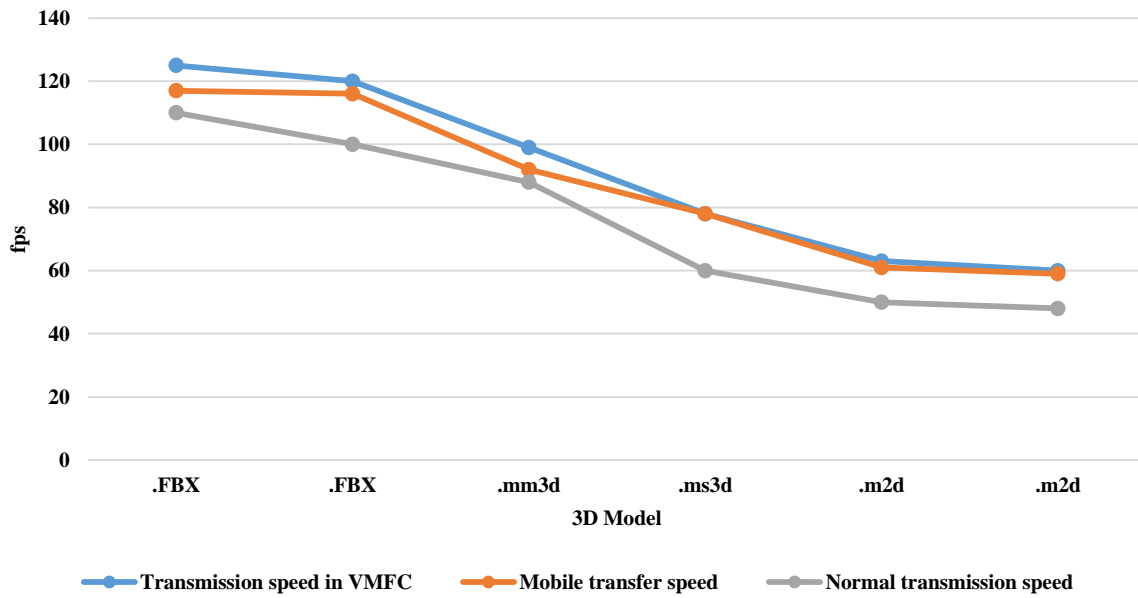


Fig. 4.    Comparison of frames transmission speed in two modes of uploading from mobile phone and uploading from VMFC.

TABLE II.        PAIRED T-TEST TO CHECK THE DIFFERENCE IN TRANSMISSION SPEED BEFORE AND AFTER USING VMFC

| Variable | level | Average | standard deviation | t | p-value |
|---|---|---|---|---|---|
| Speed | After using VMFC | 89.33 | 28.73 | 2.98 | 0.032 |
| | On mobile and without VMFC | 84.25 | 25.89 | | |

**(a) Mobile Internet**



**(b) Internet communication**
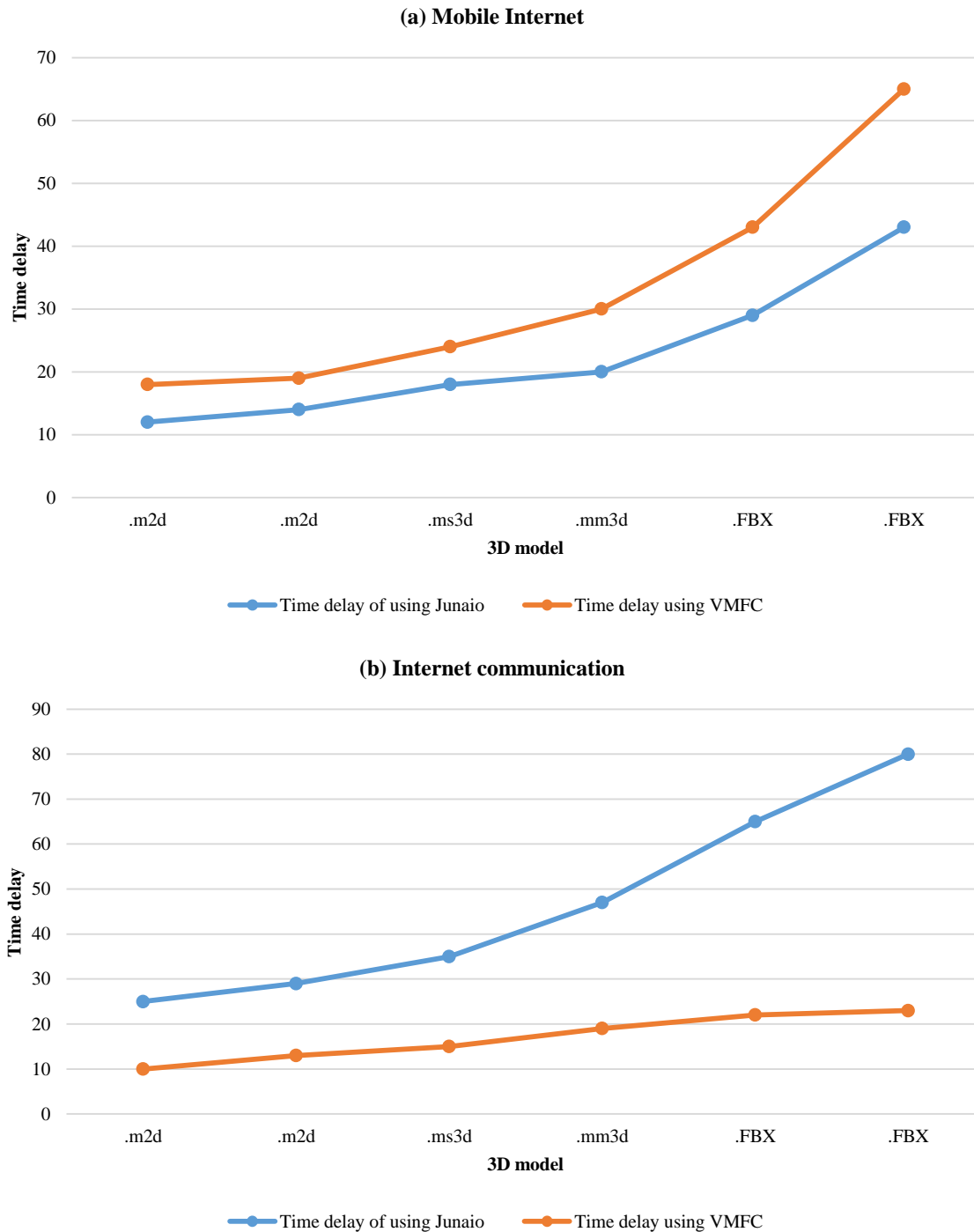


Fig. 5.  (a) Data transfer time delay in mobile internet. (b) Time delay of data transfer in Internet telecommunications.

Based on Eq. (1), Fig. 5(a) and 5(b) present the time costs of data transmission in two telecommunication networks and mobile internet, respectively. The transmission of huge amounts of data, including FBX that took place in Junaio had a maximum delay of about 56 seconds, roughly 10 seconds longer than the maximum delay on the mobile Internet network. This quantity becomes apparent when there are more requests made and a lot of data being transferred. The suggested architecture's maximum latency has been achieved utilizing mobile internet, roughly 23 seconds less than the maximum delay in Junaio on the same platform. This number indicates that VMFC offers greater performance than cloud servers. It demonstrates the benefits of a high-speed network for delivering superior service. Additionally, there is a very small- and acceptable-time delay in the transmission of small-volume data, including M2D. In VMFC, as opposed to Junaio, this value is ideal.

Additionally, it takes the Junaio service roughly five minutes for every request to validate, send, and get a response link for a new request from a mobile device. As a result, while employing both platforms, Junaio's average time delay is substantially higher than VMFC's. Paired t-analysis was used after using VMFC and before using it in Junaio to compare the time delay in the transmission of communications with the Internet during the execution of the program on the Junaio server and the time delay after using VMFC to see if there was a change in the amount. Has it just recently been produced? The specifics of this statistical study are shown in Table III and IV. The maximum delay in VMFC varies by roughly 18 seconds, and Table III demonstrates how the maximum delay has decreased after utilizing Junaio to 29.316 seconds and VMFC to 16.770 seconds.

With a value of (p=0.047), this reduction is likewise statistically significant. Table IV shows that there is a decrease in time delay with a value of (P=0.014) between the time delay in 4G Internet transmission while the software is running on the Junaio server and the time delay after utilizing VMFC. Table V shows a comparison of the implemented program with related programs from [29] and [27] in the cloud environment and mobile edge, respectively. The implemented program in Table V was an image-based augmented reality application. Based on the comparison table in [27], the comparison parameters are set. It is evident that the software used in the VMFC environment performs better than its equivalent program.

Additionally, study [29] performs better than study [27] since it was completed in an environment comparable to the fog, the edge environment, which has largely solved the problems associated with delay and waiting in cloud environments. The work [29] makes no mention of the adaptation time. Based on the average data collected in the evaluation section by computing the evaluation circumstances, the parameters in this table were obtained. Due to fewer time delays and faster data transfer speeds throughout, adopting fog processing services is more appropriate for delay-sensitive applications like augmented reality, as shown in Table V. For data in various quantities, this number varies. The benefit of employing fog is that it has decreased the time delay above the cloud in all stages.

Due to the significant delay and large user base, cloud-based program deployment requires a lot of parameters. Of course, the fact that we are unaware of the circumstances under which the programs in [27] and [29] execute leads to significant variation in the numbers, particularly in the value of the model detection time. On the other side, dynamic models are employed because there are more details and animation motions, which result in a larger volume and longer detection times.

*A. Energy Consumption in Mobile Fog Processing*

Due to their extensive coverage and low energy requirements, low-power technologies (LPWA) have opened the way for data storage in virtual mobile fog computing. The long-range system (LORA), which increases its effectiveness because it is a defined protocol for data transport, is one of these technologies. It gives coverage for kilometers or even more and consumes little electricity. In addition to LoRa, a number of wireless technologies, including IoT, WiFi, Zigbee, and 5G, can be employed for coverage areas. Low-cost fog processing has been accomplished using ZigBee technology. However, the wireless data transmission's effectiveness is diminished by the relatively short range of coverage (approximately 25 meters). Table VI provides a thorough comparison of the various IoT wireless network technologies (Zigbee, LoRa, NB-IoT, and 5G).

TABLE III. PAIRED T-TEST TO INVESTIGATE THE DIFFERENCE IN THE USE OF VMFC AND JUNAIO IN INTERNET TELECOMMUNICATIONS

| Variable | level | Average | standard deviation | t | p-value |
|---|---|---|---|---|---|
| Speed | After using VMFC | 16.77 | 5.57 | -2.63 | 0.047 |
| | After using Junaio | 84.25 | 29.31 | | |

TABLE IV. PAIRED T-TEST TO CHECK THE TIME DELAY DIFFERENCE IN USING VMFC AND JUNAIO IN 4G

| Variable | level | Average | standard deviation | t | p-value |
|---|---|---|---|---|---|
| Speed | After using VMFC | 22.27 | 11.21 | -3.68 | 0.014 |
| | After using Junaio | 32.66 | 18.04 | | |

TABLE V. COMPARISON OF THE PROGRAM IMPLEMENTED IN [27] AND [29] AND THE PROGRAM BASED ON VMFC (TIMES IN MILLISECONDS)

| | | Program based: | |
|---|---|---|---|
| parameters | VMFC | Cloud in [27] | Cloud in [29] |
| Early time | 1.8 | 3.1 | 2.4 |
| Time of diagnosis | 23.47 | 82.78 | 40.31 |
| Compliance time | 8 | 10 | -- |
| Similar sample | 0.7 | 1.5 | 0.85 |
| response time | 25 | - | 23 |
| Delay time | 18 | 23.22 | 18.7 |
| Loading time | 10 | 18 | 11.3 |
| loading time | 0.007 | 0.1 | -- |

The amount of energy used is examined in this part based on several parameters in this layer. The amount of time that each fog node spends processing data determines how much energy each fog node consumes. The fog node's energy usage rose along with the processing time. Thus, it can be concluded that the processing time at each fog node directly correlates with the energy usage in the fog. Consequently, as indicated by Eq. (2), we will have:

$$Em_{wi} \propto \frac{1}{\mu wi - \sum_{wh \in f} a_{whwi}} \quad \forall wi \in f \quad (2)$$

The energy relation in each fog node can be expressed as follows, using $e^f$ as the unit of energy consumption per unit of time:

$$Em_{wi} \propto \frac{1}{\mu wi - \sum_{wh \in f} a_{whwi}} \times e^f \quad (3)$$

The data rate, range, device count, number of gateways or base stations, and energy consumption of both gateways or base stations and sensors are the categories utilized to group all fog-based wireless network technologies in this work, as indicated in Table VI. According to this research, various fog-based wireless network solutions almost all consume the same amount of energy, as illustrated in Fig. 6. Zigbee only has a range of 25 meters, so deploying it in an urban setting is not the ideal option. To transmit and store data over a vast region, hundreds or thousands of gateways are required.

Since using technology to cover a large area while using the least amount of energy is the objective, as illustrated in Fig. 6, LoRa has been chosen as a fog-based wireless communication technology between IoT sensors and gateways that supports remote communication with minimal energy usage. Processing mobile fog is taken into account. In contrast to conventional cloud-based architecture, Fig. 7 compares the energy usage of various tasks in an edge-fog-cloud design. Additionally, it displays the position of each task or application inside the edge-fog-cloud architecture as well as the energy usage figures for each one separately. The findings demonstrated that the edge layer is laden with sensor jobs since it has sufficient capacity. Because the fog layer has enough resources to execute jobs like data transfer and storage, normal processing tasks are sequentially loaded into the fog. The edge and fog layers are unable to fulfill demanding processing duties, so all remaining requests are offloaded to the cloud layer. Fig. 8 compares the energy usage of mobile and fixed Internet using LoRa technology based on fog processing. The energy usage of telecom internet is superior to that of mobile internet, accounting for up to 34% of the overall electricity consumption. However, energy savings based on various wireless solutions based on fog processing range somewhat between 32.4% and 34.3%. Zigbee has higher energy savings since it uses less energy to transmit sensor data.

TABLE VI.     COMPARISON OF TECHNOLOGIES BASED ON MOBILE FOG PROCESSING

| Technologies based on mobile fog | Data Rate | Range | Device Count | Power consumption(gateway) | Power consumption(sen) |
|---|---|---|---|---|---|
| Zigbee | 240 Kb-ps | 25m | 250 [23]] | 2W [26] | 0.2W[25] |
| Lora | 60 Kb-ps | 15km | 12000 [28] | 35W [21] | 0.45W[22] |
| NBIOT | 250 Kb-ps | 25km | 56 [13] | 7421W[39] | 0.66W[38] |
| 5G | 25 Gb-ps | 30km | 1 mil. Per 2km [40] | 12500W[14] | 0.5W[23] |
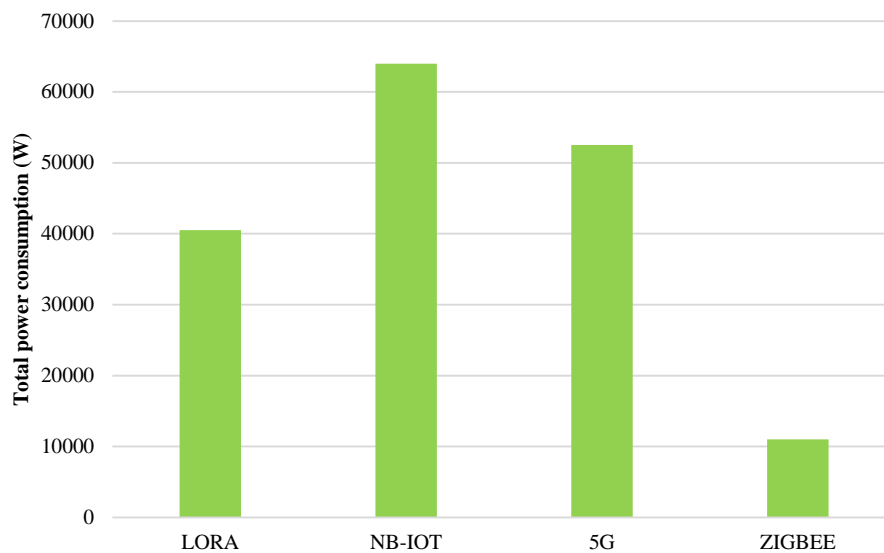


Fig. 6.   Compares the energy usage of several wireless network solutions based on mobile fog processing.
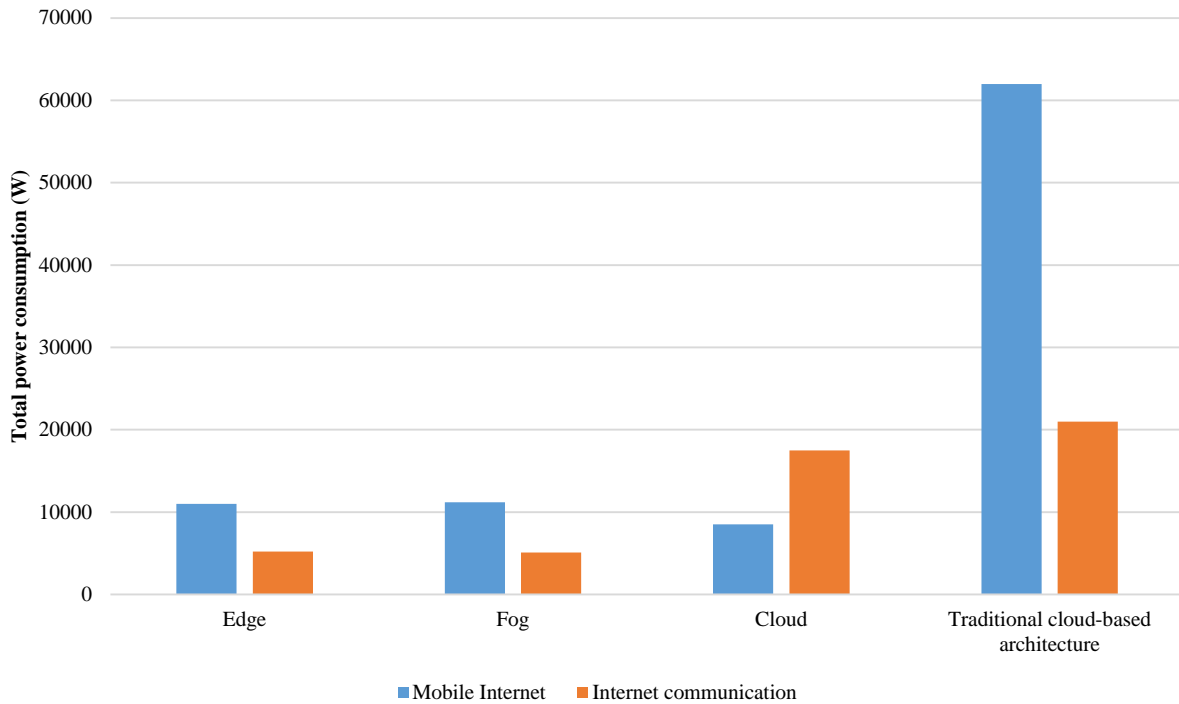
Fig. 7.   Energy consumption of telecom Internet versus mobile Internet, considering LoRa technology based on mobile fog processing.
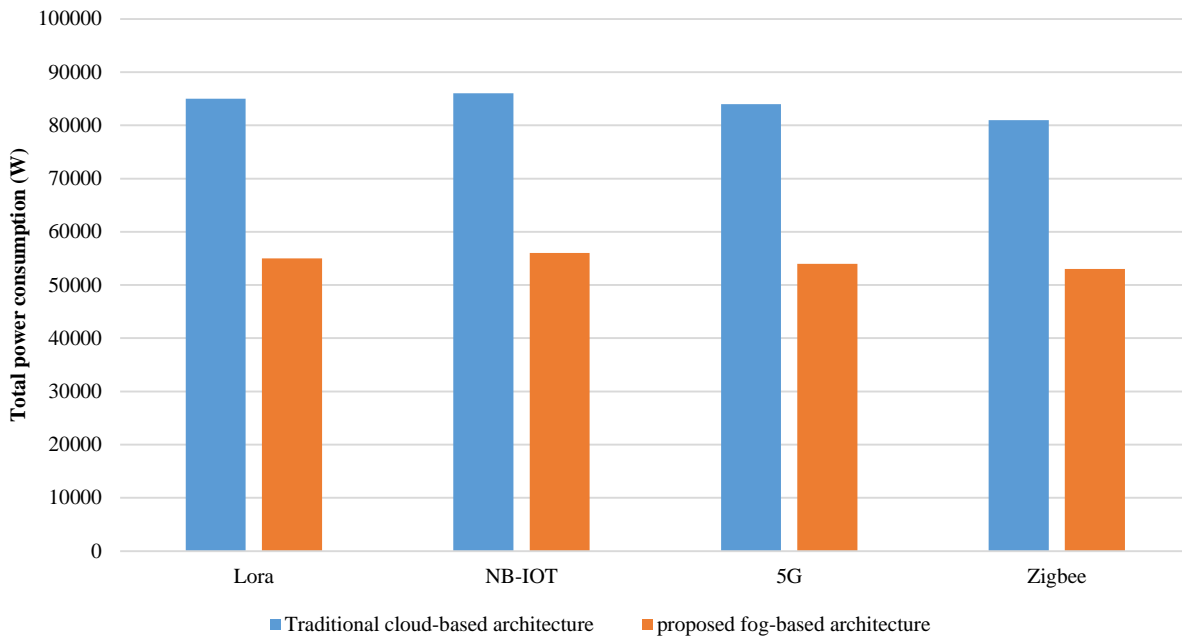


Fig. 8.   Energy saving of the proposed architecture versus the traditional cloud-based architecture, using different wireless technologies based on mobile fog processing.

## VI. CONCLUSION

The proposed method presented in this article has reduced the limitations of MCC services, including access delay, serial processing and network traffic, as well as the limitations of smart devices in running real-time programs such as augmented reality programs and programs that require. As they have more storage in the environment, it has been solved. Due

to user profile registration and encryption with digital signature, providing a unique ID for each user and software ID for each program transferred to the cloud node, using this architecture increases the security of authentication for access to resources and data. And it is not possible to reuse the unique identifier of a user by another person. The image-based augmented reality program was implemented based on the

presented method. The transfer of polygons processed on the 3D model to the screen in two modes of loading from a mobile phone and loading from VMFC was compared and it was observed that for models with a larger volume, the use of VMFC technology works faster and this is an advantage in the implementation of sensitive programs. It is delayed and immediate. Data transfer was done in two modes using Junaio and VMFC servers in two platforms, Wi-Fi internet and 4G mobile phone internet. The use of a large number of cloud nodes in mass form is necessary for a wide network of mobile devices, and this method should be able to support a large number of devices, followed by many programs, and run at an acceptable speed.

One of the limitations of this research is the small number of nodes for implementing programs, which should be resolved in future works. For future work, implementation and optimization of architecture layers to provide better and more efficient services, communication in the context of 5G networks should be given more attention, which minimizes delays.

### REFERENCES

[1] W. Shi, J. Cao, Q. Zhang, Y. Li, and L. Xu, "Edge computing: Vision and challenges," IEEE Internet Things J, vol. 3, no. 5, pp. 637–646, 2016.

[2] A. A. Khan et al., "A drone-based data management and optimization using metaheuristic algorithms and blockchain smart contracts in a secure fog environment," Computers and Electrical Engineering, vol. 102, p. 108234, 2022.

[3] S. Subbaraj, R. Thiyagarajan, and M. Rengaraj, "A smart fog computing based real-time secure resource allocation and scheduling strategy using multi-objective crow search algorithm," J Ambient Intell Humaniz Comput, pp. 1–13, 2021.

[4] R. Roman, J. Lopez, and M. Mambo, "Mobile edge computing, fog et al.: A survey and analysis of security threats and challenges," Future Generation Computer Systems, vol. 78, pp. 680–698, 2018.

[5] M. Chiang and T. Zhang, "Fog and IoT: An overview of research opportunities," IEEE Internet Things J, vol. 3, no. 6, pp. 854–864, 2016.

[6] R. Kalaria, A. S. M. Kayes, W. Rahayu, and E. Pardede, "A Secure Mutual authentication approach to fog computing environment," Comput Secur, vol. 111, p. 102483, 2021.

[7] R. Neware, K. Ulabhaje, G. Karemore, H. Lokhande, and V. Dandige, "Survey on Security Issues in Mobile Cloud Computing and Preventive Measures," in Smart Computing Paradigms: New Progresses and Challenges: Proceedings of ICACNI 2018, Volume 2, Springer, 2020, pp. 89–100.

[8] A. Kallel, M. Rekik, and M. Khemakhem, "IoT-fog-cloud based architecture for smart systems: Prototypes of autism and COVID-19 monitoring systems," Softw Pract Exp, vol. 51, no. 1, pp. 91–116, 2021.

[9] A. Munir, P. Kansakar, and S. U. Khan, "IFCIoT: Integrated Fog Cloud IoT: A novel architectural paradigm for the future Internet of Things.," IEEE Consumer Electronics Magazine, vol. 6, no. 3, pp. 74–82, 2017.

[10] K. N. Pallavi and V. Ravi Kumar, "Authentication-based access control and data exchanging mechanism of IoT devices in fog computing environment," Wirel Pers Commun, vol. 116, pp. 3039–3060, 2021.

[11] M. Trik, A. M. N. G. Molk, F. Ghasemi, and P. Pouryeganeh, "A hybrid selection strategy based on traffic analysis for improving performance in networks on chip," J Sens, vol. 2022, 2022.

[12] W. Shi, J. Cao, Q. Zhang, Y. Li, and L. Xu, "Edge computing: Vision and challenges," IEEE Internet Things J, vol. 3, no. 5, pp. 637–646, 2016.

[13] Yahya, R. O., Mahmood, N. H., Kadir, D. H., & Aziz, S. J. (2023). The Use of Factor Analysis and Cluster Analysis Methods to Identify the Most Crucial Key Factors Influencing the Psychological Stability of University Students. Polytechnic Journal of Humanities and Social Sciences, 4(1), 779-789.

[14] D. C. G. Valadares, N. C. Will, J. Caminha, M. B. Perkusich, A. Perkusich, and K. C. Gorgônio, "Systematic literature review on the use of trusted execution environments to protect cloud/fog-based Internet of Things applications," IEEE Access, vol. 9, pp. 80953–80969, 2021.

[15] S. Shukla, S. Thakur, S. Hussain, J. G. Breslin, and S. M. Jameel, "Identification and authentication in healthcare internet-of-things using integrated fog computing based blockchain model," Internet of Things, vol. 15, p. 100422, 2021.

[16] S. Wang, X. Zhang, Y. Zhang, L. Wang, J. Yang, and W. Wang, "A survey on mobile edge networks: Convergence of computing, caching and communications," Ieee Access, vol. 5, pp. 6757–6779, 2017.

[17] Y. Fan et al., "SBBS: A secure blockchain-based scheme for IoT data credibility in fog environment," IEEE Internet Things J, vol. 8, no. 11, pp. 9268–9277, 2021.

[18] N. Kumar, S. Zeadally, and J. J. P. C. Rodrigues, "Vehicular delay-tolerant networks for smart grid data management using mobile edge computing," IEEE Communications Magazine, vol. 54, no. 10, pp. 60–66, 2016.

[19] Trik, M., Mozaffari, S. P., & Bidgoli, A. M. (2021). Providing an adaptive routing along with a hybrid selection strategy to increase efficiency in NoC-based neuromorphic systems. Computational Intelligence and Neuroscience, 2021.

[20] A. Lakhan, Q.-U.-A. Mastoi, M. Elhoseny, M. S. Memon, and M. A. Mohammed, "Deep neural network-based application partitioning and scheduling for hospitals and medical enterprises using IoT assisted mobile fog cloud," Enterp Inf Syst, vol. 16, no. 7, p. 1883122, 2022.

[21] Hai, T., Alizadeh, A. A., Ali, M. A., Dhahad, H. A., Goyal, V., Metwally, A. S. M., & Ullah, M. (2023). Machine learning-assisted tri-objective optimization inspired by grey wolf behavior of an enhanced SOFC-based system for power and freshwater production. International Journal of Hydrogen Energy.

[22] D. Lanka, C. L. Veenadhari, and D. Suryanarayana, "Application of fog computing in military operations," Int J Comput Appl, vol. 164, no. 6, pp. 10–15, 2017.

[23] Mokhlesi Ghanevati, D., Khorami, E., Boukani, B., & Trik, M. (2020). Improve replica placement in content distribution networks with hybrid technique. Journal of Advances in Computer Research, 11(1), 87-99.

[24] Khezri, E., Zeinali, E., & Sargolzaey, H. (2023). SGHRP: Secure Greedy Highway Routing Protocol with authentication and increased privacy in vehicular ad hoc networks. Plos one, 18(4), e0282031.

[25] FanghuaTang, Huanqing Wang, Liang Zhang, Ning Xu, Adil M.Ahmad. Adaptive optimized consensus control for a class of nonlinear multi-agent systems with asymmetric input saturation constraints and hybrid faults. Communications in Nonlinear Science and Numerical Simulation, 126: 107446, 2023.

[26] Wenjing Wu, Ning Xu, Ben Niu, Xudong Zhao and Adil M. Ahmad, Low-Computation Adaptive Saturated Self-Triggered Tracking Control of Uncertain Networked Systems, Electronics, 12(13), 2771, 2023.

[27] S. C. Nayak, S. Parida, C. Tripathy, and P. K. Pattnaik, "Task scheduling mechanism using multi-criteria decision-making technique, MACBETH in cloud computing," in Progress in Computing, Analytics and Networking: Proceedings of ICCAN 2017, Springer, 2018, pp. 381–392.

[28] S. K. Dwivedi, R. Amin, and S. Vollala, "Smart contract and ipfs-based trustworthy secure data storage and device authentication scheme in fog computing environment," Peer Peer Netw Appl, vol. 16, no. 1, pp. 1–21, 2023.

[29] Khezri, E., Zeinali, E., & Sargolzaey, H. (2022). A novel highway routing protocol in vehicular ad hoc networks using VMaSC-LTE and DBA-MAC protocols. Wireless Communications and Mobile Computing, 2022.

[30] S. Guo, X. Zhao, H. Wang, N. Xu, Distributed consensus of heterogeneous switched nonlinear multiagent systems with input quantization and dos attacks, Applied Mathematics and Computation 456 (2023) 128127.

[31] Fabin Cheng, Ben Niu, Ning Xu, Xudong Zhao, and Adil M. Ahmad. Fault Detection and Performance Recovery Design With Deferred Actuator Replacement Via A Low-Computation Method, IEEE Transactions on Automation Science and Engineering, DOI: 10.1109/TASE.2023.3300723, 2023.

[32] Khezri, E., & Zeinali, E. (2021). A review on highway routing protocols in vehicular ad hoc networks. SN Computer Science, 2, 1-22.

[33] E. Poornima et al., "Fog robotics-based intelligence transportation system using line-of-sight intelligent transportation," Multimed Tools Appl, pp. 1–29, 2023.

[34] M. Samiei, A. Hassani, S. Sarspy, I. E. Komari, M. Trik, and F. Hassanpour, "Classification of skin cancer stages using a AHP fuzzy technique within the context of big data healthcare," J Cancer Res Clin Oncol, pp. 1–15, 2023.

[35] J. Sun, Y. Zhang, and M. Trik, "PBPHS: a profile-based predictive handover strategy for 5G networks," Cybern Syst, pp. 1–22, 2022.

[36] M. Trik, H. Akhavan, A. M. Bidgoli, A. M. N. G. Molk, H. Vashani, and S. P. Mozaffari, "A new adaptive selection strategy for reducing latency in networks on chip," Integration, vol. 89, pp. 9–24, 2023.

[37] Yanwei Zhao, Ben Niu, Guangdeng Zong, Xudong Zhao, Khalid H. Alharbi. Neural network-based adaptive optimal containment control for non-affine nonlinear multi-agent systems within an identifier-actor-critic framework, Journal of the Franklin Institute. 360 (12), pp.8118-8143, 2023.

[38] Sai Huang；Guangdeng Zong；Huanqing Wang；Xudong Zhao；K. H. Alharbi. Command Filter-Based Adaptive Fuzzy Self-Triggered Control for MIMO Nonlinear Systems With Time-Varying Full-State Constraints. International Journal of Fuzzy Systems, 2023, https://doi.org/10.1007/s40815-023-01560-8.

[39] R. Abeywickrama, M. Haviv, B. Oz, and I. Ziedins, "Strategic bidding in a discrete accumulating priority queue," Operations Research Letters, vol. 47, no. 3, pp. 162–167, 2019.

[40] S. Guan and A. Boukerche, "Intelligent edge-based service provisioning using smart cloudlets, fog and mobile edges," IEEE Netw, vol. 36, no. 2, pp. 139–145, 2022.

# Automatic Configuration of Deep Learning Algorithms for an Arabic Named Entity Recognition System

AZROUMAHLI Chaimae[1], MOUHIB Ibtihal[2], El YOUNOUSSI Yacine[3], BADIR Hassan[4]

Laboratory of Intelligent Systems and Applications (LSIA),
Moroccan School of Engineering Sciences (EMSI), Tangier, Morrocco[1, 2]
SIGL Laboratory, ENSA Tetuan, Abdel Malek Essaadi University, Tetuan, Morrocco[3]
IDS-Team, ENSA Tangier, Abdel Malek Essaadi University, Tangier, Morrocco[4]

*Abstract*—**Word embedding models have been widely used by many researchers to extract linguistic features for Natural Language Processing (NLP) tasks. However, the creation of an adequate Word embedding model depends on choosing the right language model method and architecture, in addition to fine-tuning the various parameters of the language model. Each parameter combination could result in a different model, and each model can behave differently according to the targeted NLP task. In this paper, we present an approach that combines a range of Word embedding models, multiple clustering and classification methods, and Irace for automatic algorithm configuration. The goal is to facilitate the construction of the most accurate Arabic Named Entity Recognition (NER) model for our dataset. Our approach involves the creation of different Word embedding models, the implementation of these models in different classification and clustering methods, and fine-tuning these implementations with different parameter combinations to create an Arabic NER System with the highest accuracy rate.**

*Keywords—Algorithm automatic configuration; natural language processing; named entity recognition; word embeddings; finetuning; irace*

## I. INTRODUCTION

For NLP applications like machine translation, information retrieval and sentiment analysis, it is crucial to have high-quality systems for lower tasks that return necessary features for machine learning systems [1] [2]. NER is an essential component for such tasks, its most important aspect is information extraction, and it can be carried out in two steps; the detection of the Named Entities, and the classification of these entities into a predefined set of categories (e.g., organizations, places, people, …). The term "Named Entity" was introduced during the sixth Message understanding conference [3]. The NER task was limited to the recognition of the people's names, organizations, places, temporal expressions and certain types of numerical expression [4]. These classification tags were divided afterwards into these categories: ENAMEX for people names, organizations and places, TIMEX for temporal expressions, NUMEX for numerical expression, and MISC for proper names that are not in the ENAMEX category.

NER systems utilize several linguistic features, in fact detecting these features is considered more important than the used model itself, especially when handling languages with a complex morphology like Arabic [5]. Lately, there has been a hype on using unlabeled data to learn word representation or Word Embeddings that can capture morphological, semantic and syntactic features of words, which consequently can be helpful in many learning algorithms of NLP including NER. However, there are various methods for learning Word Embeddings (e.g. Word2Vec [6], GloVe [7], FastText [8], BERT [9], ELMO [10]), and each method has many parameters that can be adjusted to create different models. Further, the machine learning algorithm that will use these Word embedding models can also have a major effect on the performance of the resulting NER system. In addition, for each model and machine learning algorithm, several training parameters can be tuned and adjusted to get more accurate results.

In this work, we adopt Irace [11] as a finetuning tool to find the most accurate NER system for our dataset. Our dataset includes two Arabic varieties: Modern Standard Arabic (MSA) and Arabic Dialects (AD) [12]. The Objective is to choose automatically one Word Embedding model from several models created using four methods (i.e., Skip-Gram, CBOW, GloVe, FastText) and one machine learning algorithm with its suitable hyperparameter combination. We use Irace to fine-tune between different created Arabic Word Embeddings, and different classification algorithms (i.e., LSTM [13], GRU [14]) and clustering algorithms (i.e., K-Mean [15], Mean-shift [16], DBSCAN [17], and Agglomerative [18]) to get the most accurate system possible for the NER task.

The rest of this paper follows this structure: Section II provides an overview of the key concepts and introduces the Irace package, a crucial component of the proposed methodology. Section III outlines the step-by-step process employed to develop the NER system. Section IV presents and analyzes the results obtained from the experiments. Finally, Section 5 concludes the work described in this paper.

## II. THE PROPOSED METHOD

In prior work [19], we have created word Embedding models with four methods (i.e. Skip-Gram, CBOW, Glove, FastText). These models were trained on three different datasets (i.e., Wikipedia, Facebook, Twitter) containing two

different Arabic varieties (i.e., MSA and Arabic Dialects). Then, we investigated the quality of the trained models using 12 hyperparameter combinations. We used different intrinsic evaluations (i.e., Word Analogy Task, Concept categorization) and different extrinsic evaluations (i.e., POS tagging, NER, Text Classification, Sentiment Analysis). In conclusion, our study raised three outcomes; The different stylistic properties of the datasets and the tuned hyper-parameters had an impact on the semantic and syntactic properties of the generated word representations and, subsequently, an impact on the NLP tasks. Further, even though the hyperparameters have a major impact on the accuracy of different NLP tasks, these changes are inconsistent and random [19].

As a consequence, we propose the solution of fine-tuning between the different hyperparameters to get the most accurate system for a specific application. Nevertheless, fine-tuning between 12 combinations to create the Word Embeddings model, and the different classification or clustering methods will be computationally expensive and time-consuming. Thus, we needed an approach that would automatically fine-tune between these hyperparameters and deduce the most accurate hyperparameter combination for a specific NLP task.

In this section, we present a detailed description of the tools that we used, afterwards in Section 3, we explain in depth the algorithms of our approach.

### A. The Irace Package

In NLP, creating an efficient system is relevant to the selection and fine-tuning of the training algorithms' parameters. In Machine Learning, this is known as the automatic algorithm's configuration. The goal is to find beneficial parameter settings to solve unseen problem instances by trying automatic learning on a set of training problem instances [11]. We opted to use the Irace package to facilitate the combined use of Word Embeddings' models and machine learning methods. Irace executes an automatic tuning of a set of parameter combinations, consequently, we avoid the manual adjusting of these parameters.

The Irace package is an R software tool that implements iterated racing procedures. It was created for the automatic configuration of optimization and decision algorithms, thus, its goal is to find the most accurate settings of an algorithm where a set of probabilities' instances is given [20],[21]. This package is suitable for our application since it can automatically configure the training algorithm where their performances depend greatly on parameter settings.

Irace deduces the most accurate algorithm configuration by implementing an elite principle on the iterated racing algorithm [20]; In the first iteration, initial algorithm configurations are randomly generated, and the best configuration is determined by a race [11]. Each configuration is evaluated on the training problem instances to set the "elite" configurations from the prior configuration iterations. Afterwards, a statistical test is used to determine the eliminated configurations once they perform worse than the other configurations. The remaining configurations will be known as the surviving configurations that will run on the next instance.

### B. The Word Embeddings Models

We opted for several Word Embeddings models using different architectures and different hyper-parameters, Table I shows the Dataset's sources and the hyperparameters used to train the models for every architecture. In prior work [19], we used a Python implementation of Word2Vec to create Skip-Gram and CBOW Word Embeddings models using Word2Vec's both architectures (i.e., Hierarchical SoftMax - HS) and Negative Sampling (NS) [22])[1]. The models were trained on four different training Arabic Datasets containing both MSA and Arabic Dialects content. We used the Glove-Python implementation to create Glove Word Embeddings models. We opted to use pre-trained word vectors created by the Facebook Artificial Intelligence Research team using Fast Text's CBOW and Skip-Gram architectures [23].

The used datasets were collected and pre-processed in prior work from different sources [24]. The first source is the online encyclopedia; Wikipedia. This corpus presents the two varieties Classical and Modern Standard Arabic. The second source is social media; Twitter and Facebook. This corpus presents the various Arabic Dialects content. The datasets were pre-processed afterwards; non-Arabic characters and diacritical marks were removed, several characters were normalized to unify the shape of some Arabic letters, and several Arabic stop words were disregarded as well [24].

### C. Machine Learning Methods

Different works have shown that the combined use of both the supervised and the unsupervised methods has a positive impact on the performance of several NLP applications [25], [26],[27]. These methods are called semi-supervised methods, where labelled and unlabeled data are used to perform certain learning tasks [28]. In our case, we harnessed large amounts of unlabeled Arabic text data and created word representations that have the potential of carrying semantic and syntactic word properties as explained in the previous section, we used relatively smaller sets of labelled data to perform the NER task as it will be explained in the next section. There is a wide range of classification and clustering algorithms that can be used as the supervised part of our application, and since we can automatically configure and fine-tune between different decision algorithms using Irace, we can utilize several algorithms. For the clustering algorithms, we chose K-mean [29], Mean-shift [16], DBSCAN [30], and Agglomerative [31]. For the classification algorithms, we chose LSTM [32] and GRU [33]. Each method had its parameters and learning activation and optimization layers that can be fine-tuned using Irace. We chose these specific machine learning algorithms since they prove to be useful for many machine learning fields other than the NLP applications like the works cited in [34], [35] and [36].

---

[1] These implementations are available at: https://github.com/AzChaimae/NLP-applications-with-Word-Embeddings-models-Extrinsic-Evaluation.git

TABLE I. MODEL'S HYPERPARAMETER CONFIGURATIONS

| | CBOW (HS) | CBOW (NS) | Skip-Gram (HS) | Skip-Gram (NS) | Glove | FastText |
|---|---|---|---|---|---|---|
| **Dataset source** | Wikipedia, Facebook, Twitter | Wikipedia, Facebook, Twitter | Wikipedia, Facebook, Twitter | Wikipedia, Facebook, Twitter | Wikipedia, Facebook, Twitter | Wikipedia |
| **Contextual window** | 3,5,7,9 | 3,5,7,9 | 3,5,7,9 | 3,5,7,9 | 3,5,7,9 | 10 |
| **Vectors' dimension** | 200,300, 400 | 200,300, 400 | 200,300, 400 | 200,300, 400 | 200,300, 400 | 300 |

## III. METHODOLOGY

### A. NER Template

To create an NER System using Word Embeddings, we opted to use annotated existing corpora along with classification and clustering algorithms. Our NER application is performed on an annotated corpus provided by the AQMAR project [37]. This dataset was preprocessed following the steps described in Section II (B). The AQMAR dataset version that we used contains 28 articles hand-annotated to nine named entities, using the BIO system tags i.e., O (outside), B-PER (Beginning of person's entity), B-MIS (Beginning of miscellaneous' entity), B-ORG (Beginning of an organization's entity), B-LOC (Beginning of location's entity), I-PER (Inside of person's entity), I-MIS (Inside of miscellaneous' entity), I-ORG (Inside of an organization's entity), I-LOC (Inside of location's entity). Table II illustrates the statistics of the NER annotated dataset and an example of the annotated tokens.

Our NER approach is illustrated in Fig. 1. The Auto NER configuration class fine-tunes between Word Embeddings models and different machine learning algorithms. The Word Embeddings models were created using Word2Vec, Glove and FastText models. The machine learning algorithms include classification and clustering methods (i.e., LSTM, GRU, K-Means, Mean-Shift, DBSCAN, and Agglomerative).

The Autoconfiguration class calls either an implementation of LSTM networks or GRU networks as classification algorithms or an implementation of K-Means, Agglomerative, DBSCAN or Mean-Shift as clustering algorithms. These algorithms were used to compute for each word representation a score of the considered classes using the BIO system adopted in the annotated corpus. Furthermore, the dataset was split into training, validation and testing sets. The word representations of the training and validation sets were fed to the chosen classification or clustering layer, followed by a sigmoid activation layer if it was set, and complied by Adam, a stochastic Optimization layer again if they were chosen by the Auto NER configuration class of Irace. The optimization of each classification and clustering hyper-parameters is achieved by creating several hyperparameter combinations using different Word Embeddings models, then ranking the results of each NER classifier or cluster with Irace.

To start building an NER system using one of several classifications and clustering algorithms in addition to one of the Word embedding models, we created an Auto NER Configuration class. Fig. 2 illustrates the created methods for our NER Auto parametrization executable Python script[2]. This script is the input of Irace Target Runner.

The Auto parameterization class contains two major methods: 1) The first method is the prediction method. It gets the clusters' prediction using the inputs set by Irace. These inputs are the Word Embedding models and the training algorithm. The NER models are created by preparing the tokens, splitting the training document from the AQMAR dataset into validation and testing sets, and then creating the weight matrix for the words in the sets after loading the chosen Word Embedding model. After defining the training algorithm, the method calls the chosen classification, clustering or activation layer into the compiler in addition to the stochastic optimizers' epochs and batch sizes. 2) The second method calculates the accuracies of the created NER model, by predicting the probabilities of the model, reducing the probability array to speed up the compilation time, and then returning the accuracy value that will be ranked using Irace.

The main objective of Irace is to minimize the cost value returned by the target algorithm, to find the best solution. In our case, the returned cost value of the target algorithm runner is the NER model accuracies multiplied by -1 before returning it to Irace. To calculate the accuracy of each NER model which is the cost value used to find the best solution, we opted for the F1 score if it's a classification method as it was used in [38], and the purity score if it's a clustering method.

Due to the accuracy paradox, which asserts that the accuracy score is unclear when evaluating classification models, the F1 score was utilized to evaluate classification models rather than accuracy. To measure a model's performance, the F1 score uses Precision P and Recall R as shown in Eq. (1).

$$F_1 = \frac{2}{R^{-1} + P^{-1}} = 2 \cdot \frac{P \cdot R}{P + R} \qquad (1)$$

$$P = \frac{number\ of\ true\ postives}{number\ of\ true\ positives + number\ of\ false\ positives} \qquad (2)$$

---

[2] Our Auto parametrization python implementation is available at: https://github.com/AzChaimae/Auto-parametrization-for-NLP-application-.git

TABLE II.        STATISTICS OF THE NER ANNOTATED CORPUS

| Number of tokens | Examples of the annotated tokens | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 57858 | ... | مرورا | بنظريات | التوحيد | الكبرى | ، | و | انتهاء | بنظرية | الأوتار | الفائقة | . | ... |
|  | ... | O | B-MIS | I-MIS | I-MIS | O | O | O | B-MIS | I-MIS | I-MIS | O | ... |
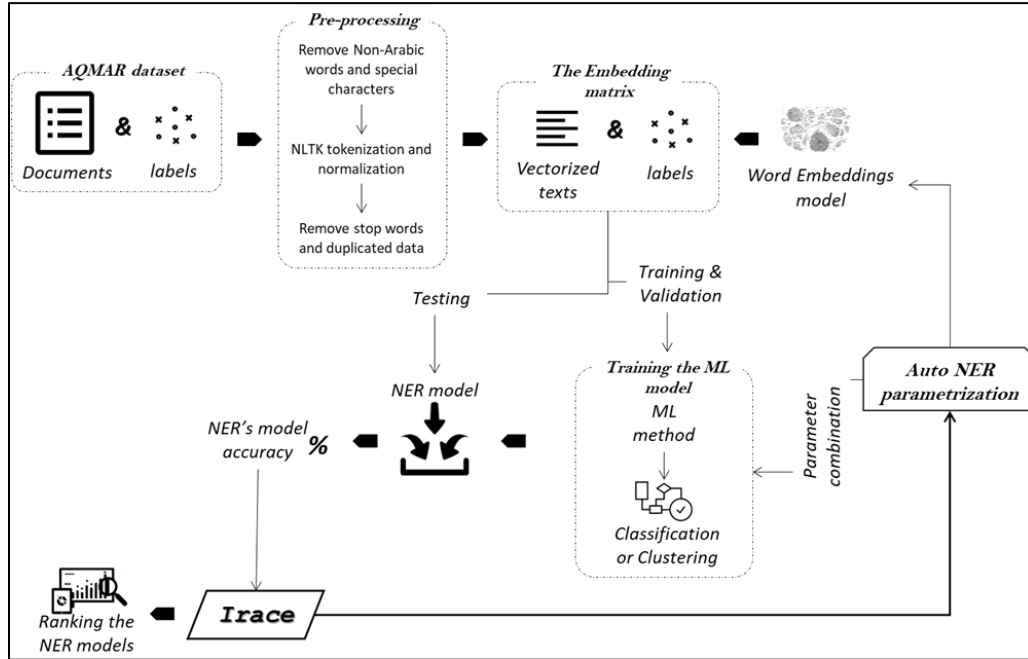


Fig. 1.   NER approach using word embeddings.
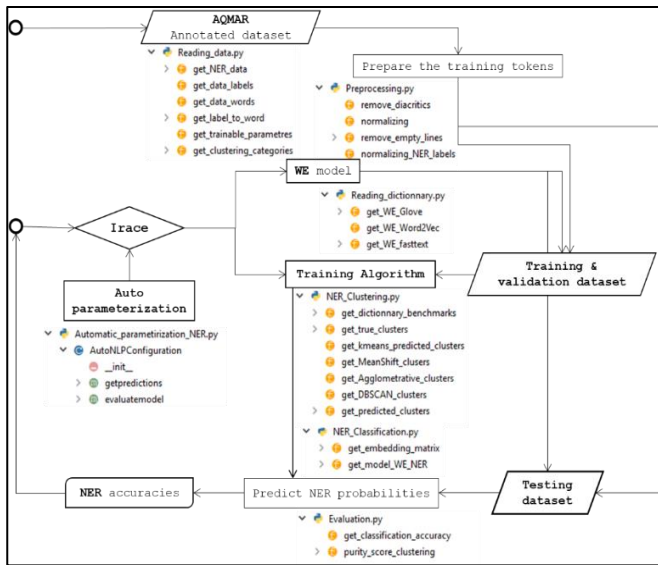


Fig. 2.   Auto NER configuration.

$$R = \frac{number\ of\ true\ postives}{number\ of\ true\ positives + number\ of\ false\ negatives} \qquad (3)$$

The purity score $purity(\Omega, \mathbb{C})$ is calculated by assigning for each cluster the most frequent class in this cluster, then the accuracy of the assigned class is measured by counting the number of the correct assigned classes and dividing it by $N$ the

number of clusters in Eq. (4). $\Omega$ presents the set of clusters, and $\mathbb{C}$ is the set of classes.

$$purity(\Omega, \mathbb{C}) = \frac{1}{N} \sum_k \max_j |\omega_k \cap c_j|$$
$$\Omega = \{\omega_1, ..., \omega_K\}, \quad \mathbb{C} = \{c_1, ..., c_J\} \qquad (4)$$

### B. Autoconfiguring NER

*1) Parameter's file.* To configure an algorithm, Irace requires a text file that contains all parameters to be tuned, including their type (categorical, ordinal, real, and integer) and sets of their possible values. The algorithm must be prepared to be configured externally with any valid parameter combination from the parameters' file. This was taken into account while creating the Auto NER Configuration class. Our parameters file contains all the parameters that can be taken by the NER auto parametrization class: Embedding file, Method, Flatten Layer, Global Average Pooling Layer, LSTM Layer, LSTM Dropout Layer, GRU Layer, GRU Dropout, GRU recurrent Dropout, Dense activation, Compile optimizer, The Number of batch size, The Number of epochs, K-Means, Mean-shift, DBSCAN or Agglomerative.

*2) Forbidden parameter combinations.* In addition to the parameters file, Irace provides the option of declaring sets of forbidden parameter combinations. For the Automatic NER parametrization class, several parameter combinations will result in a compilation error or will not be logical to compile.

There is a total of 15 forbidden parameter combinations. If the clustering method was chosen by Irace, the parameters related to the classification methods would not be finetuned, and vice versa for a classification method. Furthermore, one classification or clustering method has to be chosen to train the training weight matrix, the different dense activation and compile optimizer layers can be overlayered and fine-tuned. The rest of the forbidden parameter combinations were set to avoid error compilations.

The total number of possible parameter combinations is around 10 648 combinations, while the mean compilation time is 1.5 to 2 hours depending on the Embedding file the training method and the machine performance. To minimize the compilation time, we had to use the parallelization option offered by Python and Irace to use 23 parallel multiprocessing sessions.

## IV. RESULTS AND DISCUSSION

The objective of this experimentation is to rank the performance of the different Word embedding models, classification layers and clustering methods in an NER system. The different parameter combinations produced some impressive accuracies, while the higher accuracy being 0,9536 was achieved by training a CBOW model using an LSTM neural network, a SoftMax dense activation, and an Adam compile optimizer. Irace tuned between 1024 parameter combinations to get the best result.

To properly rank all the accuracies, we divided them into four quartiles. The first one contains the best 25% of the accuracies, the second one contains the next 25% best accuracies and so forth. Table III shows the intervals of the quartiles.

Fig. 3 illustrates the different training algorithms that achieved accuracies in the four quartiles. The first observation we can conduct from these results is that the classification algorithms outperformed the clustering ones since the best 25% of the accuracies were obtained by GRU and LSTM neural networks. In the second and third quartiles, the majority of the accuracies refer to the clustering algorithms. While the fourth quartile represents the lowest accuracies obtained by classification algorithms. From Fig. 3 (b), it's obvious that the accuracy performances of the algorithms that belong to the same category (classification or clustering) are relatively similar. So, besides the machine learning approach, the training hyperparameters could highly affect the accuracy of an algorithm.

In the previous graphs, we noticed that even though the best results ranked by Irace were obtained by the classification methods, several mediocre accuracies were also obtained by these classification methods, this can be explained by the fact that we used several layers to create the classification models. Fig. 4 and Fig. 5 illustrate the performance of LSTM and GRU layers in the four accuracy quartiles. LSTM and GRU layers performed relatively differently for both algorithms. The maximum batch size had better results for LSTM, and a minimum batch size gave better results for GRU. However, a minimum number of epochs performed better for LSTM and GRU. Furthermore, SoftMax and Sigmoid dense activations outperformed the ReLU dense activation, and the Adam optimizer architecture resulted in the majority of accuracies in the first quartile for both LSTM and GRU algorithms.

TABLE III. THE QUARTILES OF ACCURACIES

|  | Quartile 1 | Quartile 2 | Quartile 3 | Quartile 4 |
|---|---|---|---|---|
| **Max** | 0,9536773 | 0,90623109 | 0,86445103 | 0,4216347 |
| **Min** | 0,90640394 | 0,86495761 | 0,42272924 | 0,3184785 |
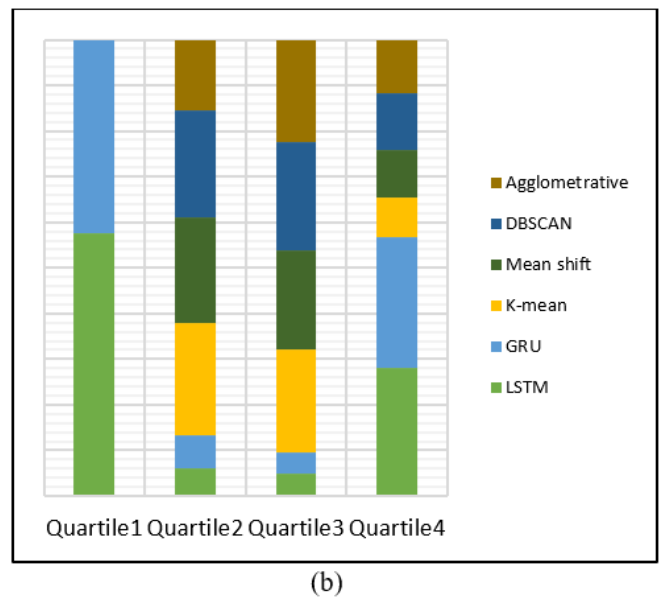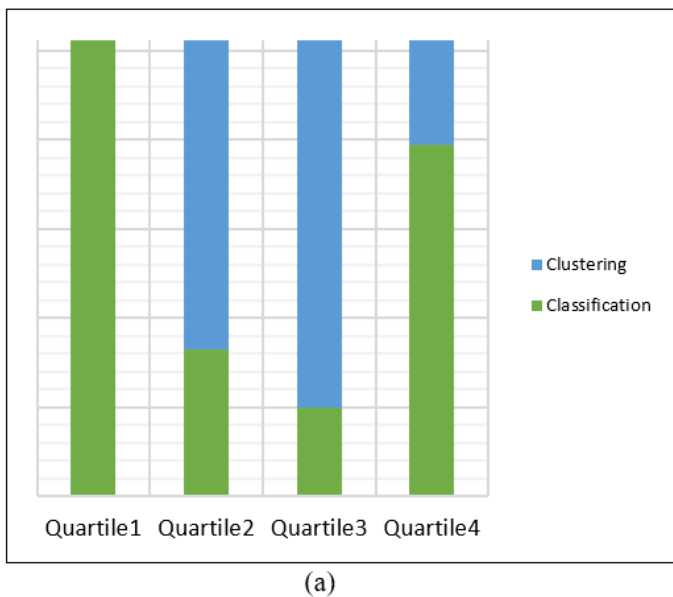


Fig. 3. (a) Classification vs. clustering performances. (b) The performance of all the different classification and clustering methods.

Each training algorithm resulted in both good and mediocre accuracies. Fig 6 illustrates the scale accuracies of the different training algorithms. This illustration enables us to study the distributional characteristics of the accuracy level of each algorithm. Consistently, the median of each box plot of each training algorithm is relatively the same; around 0.86 for clustering algorithms, and 0.89 for classification algorithms. The upper quartile of the clustering algorithms is around 0.93, but the lower quartile of the classification algorithms is around 0.41. The clustering algorithms, however, had an upper quartile of 0.87 but a lower quartile of just around 0.83. For GRU and LSTM, the box plots are comparatively long which means that there is a range of results that behaved differently as a result of different factors. On the contrary, for Agglomerative, K-Means, mean-shift, and DBSCAN, the box plots were significantly shorter with few outliers, which means that even though they were different factors including the Word Embeddings' models, the accuracies for clustering methods had a high level of agreement.

All of the parameters and factors that were used affect the accuracy of a model and its performance in an NLP application, thus, Irace and the use of Word Embeddings was the ideal solution to find the parameters combination that will result in the most accurate model for a NER system or any other NLP applications.
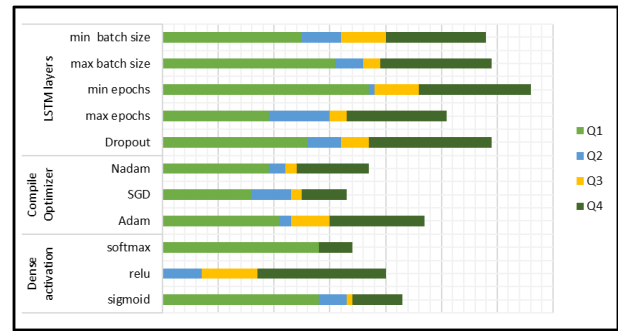


Fig. 4.    The performance of the LSTM parameters.
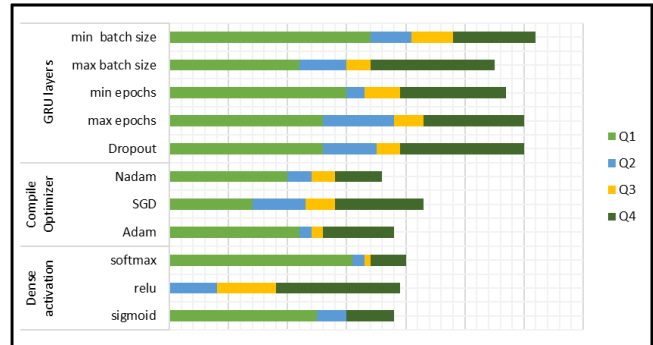


Fig. 5.    The performance of the GRU parameters.
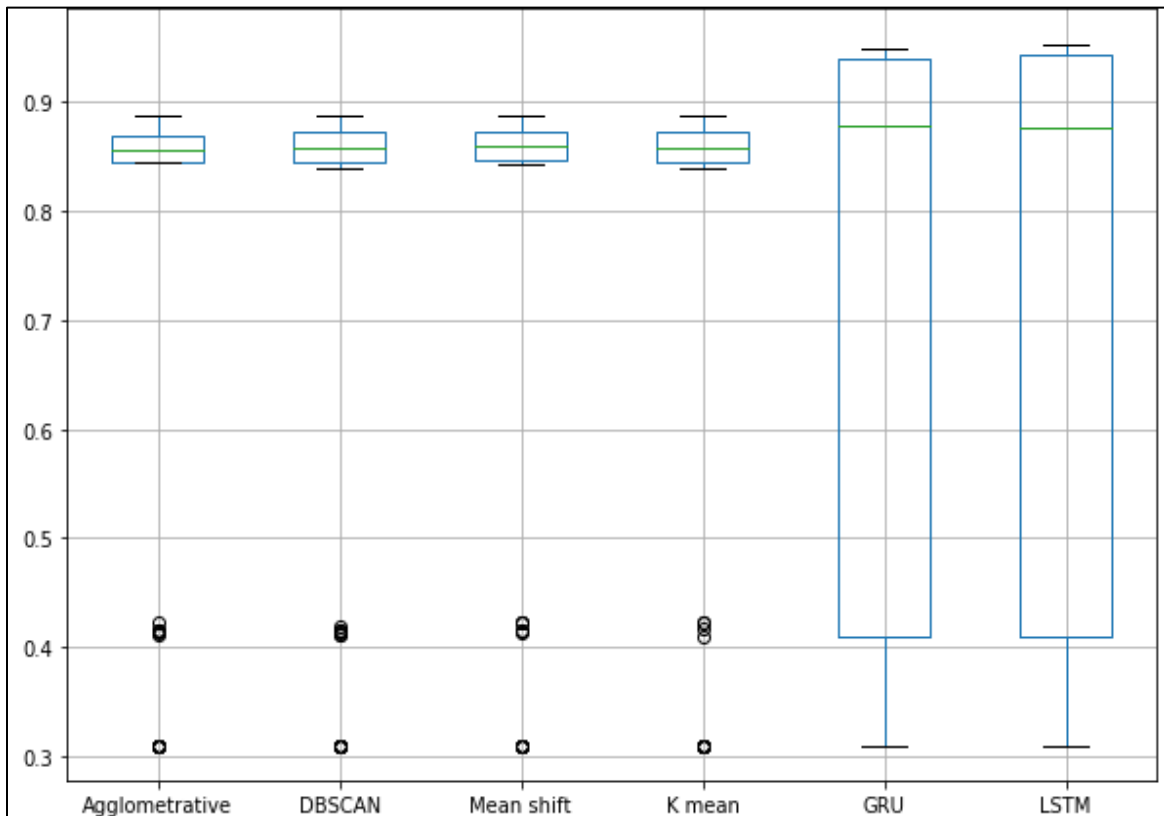


Fig. 6.    The distributional scale scores of the training algorithms.

## V. Conclusion

In this paper, we have proposed a NER approach that fine-tunes between different Word Embedding models and different hyperparameters of a different machine learning algorithm to obtain the most accurate NER system. The Word Embedding models were trained on different Arabic datasets that we collected from different sources to obtain all the Arabic varieties. The NER models were obtained by training the word Embedding representations of annotated Named Entities datasets, the training algorithms included several classification and clustering methods. The Irace package served as an automatic parameter configuration and optimization solution for an Arabic NER system. We have developed a program that was fed to the Irace package, it trains the Word Embeddings representation of the annotated Named Entities according to the selected parameters combination and returns the model accuracy that was ranked by Irace. The most accurate NER model achieved an accuracy of 0.9536.

Several promising directions remain to be explored using Irace and Word Embeddings models; other uprisings Word Embeddings models like Elmo, Bert and XLNET could result in more accurate systems for NER and other NLP applications.

## References

[1] D. Khurana, A. Koli, K. Khatter, and S. Singh, "Natural language processing: state of the art, current trends and challenges," Multimed. Tools Appl., vol. 82, no. 3, pp. 3713–3744, 2023, doi: 10.1007/s11042-022-13428-4.

[2] A. Shoufan and S. Al-Ameri, "Natural Language Processing for Dialectical Arabic: A Survey," pp. 36–48, 2015, [Online]. Available: http://www.aclweb.org/anthology/W15-3205

[3] Y. Benajiba and P. Rosso, "ANERsys 2 . 0 : Conquering the NER Task for the Arabic Language by Combining the Maximum Entropy with POS-tag Information," 3rd Indian Int. Conf. Artif. Intell., pp. 1814–1823, 2007.

[4] Y. Benajiba, P. Rosso, and J. M. Bened Ruiz, "ANERsys : An Arabic Named Entity Recognition System Based on Maximum Entropy," CICLing 2007, pp. 143–153, 2007.

[5] G. Lample, M. Ballesteros, S. Subramanian, K. Kawakami, and C. Dyer, "Neural architectures for named entity recognition," in 2016 Conference of the North American Chapter of the Association for Computational Linguistics: Human Language Technologies, NAACL HLT 2016 - Proceedings of the Conference, 2016, pp. 260–270. doi: 10.18653/v1/n16-1030.

[6] T. Mikolov, K. Chen, G. Corrado, and J. Dean, "Efficient Estimation of Word Representations in Vector Space," CrossRef List. Deleted DOIs, vol. 1, pp. 4069–4076, Jan. 2013, doi: https://doi.org/10.48550/arXiv.1301.3781.

[7] J. Pennington, R. Socher, and C. Manning, "Glove: Global Vectors for Word Representation," in Proceedings of the 2014 Conference on Empirical Methods in Natural Language Processing (EMNLP), 2014, pp. 1532–1543. doi: 10.3115/v1/D14-1162.

[8] P. Bojanowski, E. Grave, A. Joulin, and T. Mikolov, "Enriching Word Vectors with Subword Information," Anal. Methods, vol. 5, no. 3, pp. 729–734, Jul. 2016, doi: https://doi.org/10.48550/arXiv.1607.04606.

[9] J. Devlin, M.-W. Chang, K. Lee, and K. Toutanova, "BERT: Pre-training of Deep Bidirectional Transformers for Language Understanding," arXiv Prepr. arXiv1810.04805, 2018, doi: arXiv:1811.03600v2.

[10] M. E. Peters et al., "Deep contextualized word representations," in Proceedings of the 2018 Conference of the North American Chapter of the Association for Computational Linguistics: Human Language Technologies, 2018, pp. 2227–2237. doi: 10.18653/v1/N18-1202.

[11] M. López-Ibáñez, J. Dubois-Lacoste, L. Pérez Cáceres, M. Birattari, and T. Stützle, "The irace package: Iterated racing for automatic algorithm configuration," Oper. Res. Perspect., vol. 3, pp. 43–58, 2016, doi: 10.1016/j.orp.2016.09.002.

[12] B. Mouaz, B. H. Abderrahim, and E. Abdelmajid, "Speech recognition of Moroccan dialect using hidden Markov models," IAES Int. J. Artif. Intell., vol. 8, no. 1, pp. 7–13, 2019, doi: 10.11591/ijai.v8.i1.pp7-13.

[13] R. Siddalingappa and K. Sekar, "Bi-directional long short term memory using recurrent neural network for biological entity recognition," IAES Int. J. Artif. Intell., vol. 11, no. 1, p. 89, 2022, doi: 10.11591/ijai.v11.i1.pp89-101.

[14] H. Elzayady, M. S. Mohamed, K. M. Badran, and G. I. Salama, "Detecting Arabic textual threats in social media using artificial intelligence: An overview," Indones. J. Electr. Eng. Comput. Sci., vol. 25, no. 3, p. 1712, 2022, doi 10.11591/ijeecs.v25.i3.pp1712-1722.

[15] W. Yang, H. Long, L. Ma, and H. Sun, "Research on clustering method based on weighted distance density and k-means," Procedia Comput. Sci., vol. 166, pp. 507–511, 2020, doi: 10.1016/j.procs.2020.02.056.

[16] D. Comaniciu and P. Meer, "Mean shift: A robust approach toward feature space analysis," IEEE Trans. Pattern Anal. Mach. Intell., vol. 24, no. 5, pp. 603–619, 2002, doi: 10.1109/34.1000236.

[17] R. Zhang, J. Qiu, M. Guo, H. Cui, and X. Chen, "An Adjusting Strategy after DBSCAN," IFAC-PapersOnLine, vol. 55, no. 3, pp. 219–222, 2022, doi: 10.1016/j.ifacol.2022.05.038.

[18] T. Li, A. Rezaeipanah, and E. S. M. Tag El Din, "An ensemble agglomerative hierarchical clustering algorithm based on clusters clustering technique and the novel similarity measurement," J. King Saud Univ. - Comput. Inf. Sci., vol. 34, no. 6, pp. 3828–3842, 2022, doi: 10.1016/j.jksuci.2022.04.010.

[19] A. Chaimae, M. Rybinski, E. Y. Yacine, and J. F. A. Montes, "Comparative study of Arabic Word Embeddings : Evaluation and Application," Int. J. Comput. Inf. Syst. Ind. Manag. Appl. ISSN 2150-7988, vol. 12, pp. 349–362, 2020, [Online]. Available: http://www.mirlabs.org/ijcisim/volume_12.html

[20] A. J. Nebro, C. Barba-González, M. López-Ibáñez, and J. García-Nieto, "Automatic configuration of NSGA-II with jMetal and irace," GECCO 2019 Companion - Proc. 2019 Genet. Evol. Comput. Conf. Companion, pp. 1374–1381, 2019, doi: 10.1145/3319619.3326832.

[21] M. López-ibáñez, L. P. Cáceres, J. Dubois-lacoste, T. Stützle, and M. Birattari, The irace Package : User Guide. 2018. doi: 10.1080/19463138.2012.694818.

[22] R. Adipradana, B. P. Nayoga, R. Suryadi, and D. Suhartono, "Hoax analyzer for Indonesian news using rnns with fasttext and glove embeddings," Bull. Electr. Eng. Informatics, vol. 10, no. 4, pp. 2130–2136, 2021, doi: 10.11591/eei.v10i4.2956.

[23] A. Joulin, E. Grave, P. Bojanowski, and T. Mikolov, "Bag of Tricks for Efficient Text Classification," in Proceedings of the 15th Conference of the European Chapter of the Association for Computational Linguistics, 2017, pp. 427–431. doi: 1511.09249v1.

[24] A. Chaimae, Y. El Younoussi, O. Moussaoui, and Y. Zahidi, "An Arabic Dialects Dictionary Using Word Embeddings," Int. J. Rough Sets Data Anal., vol. 6, no. 3, pp. 18–31, Jul. 2019, doi: 10.4018/IJRSDA.2019070102.

[25] M. A. S. Md Afendi and M. Yusoff, "A sound event detection based on hybrid convolution neural network and random forest," IAES Int. J. Artif. Intell., vol. 11, no. 1, p. 121, 2022, doi: 10.11591/ijai.v11.i1.pp121-128.

[26] M. Hadni, S. A. Ouatik, and A. Lachkar, "Effective Arabic Stemmer Based Hybrid Approach for Arabic Text Categorization," Int. J. Data Min. Knowl. Manag. Process, vol. 3, no. 4, pp. 1–14, 2013, doi: 10.5121/ijdkp.2013.3401.

[27] R. Boujelbane, M. E. Khemakhem, S. Ben Ayed, and L. H. Belguith, "Building bilingual lexicon to create Dialect Tunisian corpora and adapt language model," Proc. Second Work. Hybrid Approaches to Transl. pages 88–93, Sofia, Bulg. August 8, 2013. c 2013 Assoc. Comput. Linguist., pp. 88–93, 2013.

[28] J. E. van Engelen and H. H. Hoos, "A survey on semi-supervised learning," Mach. Learn. 109, pp. 373–440, 2019, doi: 10.1007/s10994-019-05855-6.

[29] J. Yadav and M. Sharma, "A Review of K-mean Algorithm," Int. J. Eng. Trends Technol., vol. 4, no. 7, pp. 2972–2976, 2013.

[30] B. Ma, C. Yang, A. Li, Y. Chi, and L. Chen, "A Faster DBSCAN Algorithm Based on Self-Adaptive Determination of Parameters," Procedia Comput. Sci., vol. 221, pp. 113–120, Jan. 2023, doi: 10.1016/j.procs.2023.07.017.

[31] B. Walter, K. Bala, M. Kulkarni, and K. Pingali, "Fast agglomerative clustering for rendering," in RT'08 - IEEE/EG Symposium on Interactive Ray Tracing 2008, Proceedings, 2008, pp. 81–86. doi: 10.1109/RT.2008.4634626.

[32] M. Sundermeyer, R. Schlüter, and H. Ney, "LSTM neural networks for language modelling," in 13th Annual International Speech Communication Association, 2012, pp. 194–197.

[33] R. Jozefowicz, W. Zaremba, and I. Sutskever, "An empirical exploration of Recurrent Network architectures," in 32nd International Conference on Machine Learning, ICML 2015, 2015, pp. 2342–2350.

[34] S. Patankar, M. Phadke, and S. Devane, "Wiki sense bag creation using multilingual word sense disambiguation," IAES Int. J. Artif. Intell., vol. 11, no. 1, p. 319, 2022, doi: 10.11591/ijai.v11.i1.pp319-326.

[35] C. Huang and G. Qin, "Low-rank matrix optimization for video segmentation research," Indones. J. Electr. Eng. Comput. Sci., vol. 6, no. 1, pp. 36–41, 2017, doi: 10.11591/ijeecs.v6.i1.pp36-41.

[36] A. S. Abdalkafor and S. A. Aliesawi, "Applying of (SOM, HAC, and RBF) algorithms for data aggregation in wireless sensors networks," Bull. Electr. Eng. Informatics, vol. 11, no. 1, pp. 354–363, 2022, doi: 10.11591/eei.v11i1.3462.

[37] B. Mohit, N. Schneider, R. Bhowmick, K. Oflazer, and N. A. Smith, "Recall-oriented learning of named entities in Arabicwikipedia," EACL 2012 - 13th Conf. Eur. Chapter Assoc. Comput. Linguist. Proc., pp. 162–173, 2012.

[38] A. S. M. Afendi and M. Yusoff, "Review of anomalous sound event detection approaches," IAES Int. J. Artif. Intell., vol. 8, no. 3, pp. 264–269, 2019, doi: 10.11591/ijai.v8.i3.pp264-269.

# Greenhouse Horticulture Automation with Crops Protection by using Arduino

Jamil Abedalrahim Jamil Alsayaydeh[1]*, Mohd Faizal bin Yusof[2], Chee Kai Hern[3],
Mohd Riduan AHMAD[4], Vadym Shkarupylo[5], Safarudin Gazali Herawan[6]

Department of Electronics & Computer Engineering Technology-Fakulti Teknologi Kejuruteraan Elektrik & Elektronik (FTKEE),
Universiti Teknikal Malaysia Melaka (UTeM), Melaka, Malaysia[1, 3]
Department-Homeland Security-Faculty of Resilience, Rabdan Academy, Abu Dhabi, United Arab Emirates[2]
Atmospheric Science and Disaster Management Research Group (ThorRG), CeTRI, Universiti Teknikal Malaysia Melaka,
Hang Tuah Jaya, Melaka, Malaysia[4]
Department of Computer Systems- Networks and Cybersecurity National University of Life and Environmental Sciences of
Ukraine, Kyiv, Ukraine[5]
Industrial Engineering Department-Faculty of Engineering, Bina Nusantara University, Jakarta, Indonesia 11480[6]

*Abstract*—**Agriculture significantly contributes to economic growth, generating employment opportunity also simulating the small-scale agriculture experiences. However, unforeseeable weather patterns, natural disasters, and unwelcome intruders are significant threat which brings severe financial losses for the owner. To overcome these challenges, this study aims to develop IoT-based automation greenhouse integrated with intrusion detection and prevention system. Automation greenhouse provides optimal environmental conditions for crop growth and enhances agricultural productivity, additionally inclusion of intrusion detection and prevention practices could detect and give immediate responses towards intrudes approaches. The automation greenhouse with intrusion detection and prevention with IoT-based provides the real-time monitoring and control as instant intrusion notification will be send to user through mobile application remotely. Thus, IoT-based automation greenhouse invention provides the sustainable environment condition for crop growth and reducing crop losses from treats.**

*Keywords—IoT-based; automation greenhouse intrusion detection and prevention; real-time monitoring*

## I. INTRODUCTION

Greenhouse horticulture involves a completely enclosed structure that separates the indoor environment from the external environment, creating ideal conditions for plant growth [1]. Typically, a framed structure is covered entirely with transparent cladding that allows sunlight to penetrate into the greenhouse. Prefect environmental condition accelerates the speed of plant growth, increase the crops productivity, and shorten the harvest duration also minimize the effect from pests or diseases [2]. In contrast to the traditional farming practices of ancient times, where farmers relied primarily on their experience and visual observations, modern greenhouse horticulture leverages advanced technology for precision and efficiency. Historically, the reliance on visual observations often led to inaccuracies and occasional mistakes in managing crops, which could have significant negative consequences for yields. As the global population continues to grow, so does the demand for food production. With the emergence of Industry 4.0, technologies are occupying the agriculture sector, leading to the development of IoT-based greenhouse systems. IoT-

based systems are equipped with an array of sensors and telecommunication technologies that gather data on the greenhouse's conditions. The data collected by these systems are transmitted to cloud platforms through network interconnections, where they are recorded and analyzed to improve crop productivity [3]. High-tech urban agriculture (HTUA) is an innovative solution applied in big cities like Amsterdam, where space is limited. It incorporates environment controlling systems and horticultural lighting to optimize crop growth and maximize the harvest quantity within a shorter duration. As a result, the Netherlands has become one of the world's most food-productive countries, relying heavily on exporting agricultural goods. This paper aims to explore the advantages of IoT-based greenhouse systems and HTUA in enhancing food production, sustainability, and efficiency in the agriculture sector [4], [5]. The agriculture industry has always been vulnerable to risks that can cause significant crop reduction, one of which is the intrusion of wild animals. Traditional methods of deterring such intrusions, including scarecrows and physical fences, have limitations in terms of effectiveness and cost-efficiency [6]. However, over time, birds become familiar with scarecrows and their effective-ness is reduced. The destruction caused by these animals can resulted up to a 50% loss in farmers' finances. In India, the elephant-human conflict has shown the intensity of the intrusion of wild animals, as elephants cross human habitats to raid crops, posing a menace to both lives and property [7], [8], [9]. Adding to the problem, there are also unpleasant thefts who steal valuable crops from owners and sell them for personal benefits. Some farmers resort to armed protection, but this is illegal and only limited to certain occupations such as policemen or bodyguards. In Malaysia, legally owned guns are only available to those who need to protect themselves from predators or to safeguard their property. However, it is crucial to remember that with power comes responsibility, and the intentional shooting of someone can result in strict penalties, including the death penalty. This paper aims to explore the challenges of crop protection against wild animals and theft in the agriculture industry and discuss possible solutions to mitigate these risks. Some farmers have employed a range of techniques to address these challenges. Some have turned to

wire-netting fencing, which, while providing a physical barrier, remains vulnerable to larger animals. Electric fencing, on the other hand, is an effective deterrent but has drawbacks, including high electricity consumption and the need for government approval due to wildlife regulations [10]. Conventional greenhouse agriculture struggles to maintain optimal temperature and humidity levels for plant growth during hot weather, resulting in stunted growth and plant death. Manual operation of the greenhouse makes it difficult to obtain accurate environmental parameters to support plant growth and maximize crop production. Additionally, there is a lack of security to protect against pest attacks and theft of crops by intruders, both human and wild animals. An automated greenhouse can revolutionize the monitoring and controlling management with technology, allowing for optimal environmental conditions through sensors and automatic controls while providing high-level security against crop theft and harm to young seedlings. This work aims to develop an advanced and sustainable automation greenhouse system to increase crop production while implementing an intrusion detection and prevention system to protect against attacks by wild animals and theft. The system integrates with cloud analytics to enhance traditional greenhouse technology. The adoption of this automated greenhouse with IoT technology holds the potential to revolutionize crop productivity in the agriculture sector, allowing for remote monitoring and control through a dedicated mobile application. [11], [12], [13]. Motivated by the merits of greenhouse horticulture automation with crop protection this paper presents a laser fence mechanism, alarming system, and automation gate for intrusion detection and prevention. The installation of a laser fence intrusion detection system will enhance security by alerting researchers of any intrusion into the greenhouse. Additionally, an automated gate will respond accordingly to ensure the safety and security of the greenhouse. The Blynk application and ThingSpeak cloud database provide real-time monitoring and control of the greenhouse environment, while weather condition monitoring, internet speed, and accuracy of intrusion detection were analyzed and tested. The study successfully provided an efficient solution to maximize crop production and ensure crop safety against natural disasters and unauthorized access.

The remainder of this paper shall be arranged in the following manner: Section II will introduce related research. Our mechanism is motivated and described in Section III, followed up by related results and discussion in Section IV. Finally, in Section V, we will conclude the paper and outline potential areas of future research.

## II. RELATED WORK

According to [14], automated greenhouse systems are crucial for efficiently controlling the climate and other environmental conditions within greenhouses. With the world's increasing population, the need for sustainable food production has become a significant concern. These systems often rely on microcontrollers, such as the Atmega328, as their central control units. These automated greenhouse systems are equipped with various sensors, including temperature, soil moisture, humidity, and light sensors. These sensors work together to create and maintain optimal growing conditions for plants. The microcontroller collects data from these sensors and, based on predefined threshold values, generates digital commands to control temperature, humidity, water valves, and even trigger light-dependent resistors (LDRs) when necessary. In [15], an Automatic Watering System based on Arduino was developed to address the challenge of controlling the precise amount of water needed for plant growth. The system utilizes a soil moisture sensor to detect the moisture level in soil and automatically irrigate the plant according to its demand. The sprinkler system determines the watering progress based on the received moisture level with-out any human intervention. According to [16], an automation irrigation project has been developed based on the readings from a soil moisture sensor. The Arduino microcontroller is used to control all the devices connected to the system. A drip irrigation system is used to efficiently water plants through narrow tubes and valves, and a Liquid Crystal Display (LCD) displays the moisture level of the soil. The relay module is used to turn ON and OFF the water pump based on the voltage readings received by the microcontroller, which is in turn based on the moisture level of the soil. According to the book by [17], an Internet of Things (IoT)-based system for greenhouse farming using Arduino and an ESP8266 module. This project aims to control and monitor environmental parameters within a greenhouse where Aloe Vera crops are cultivated. The system is integrated with the Blynk application via cloud computing, enabling remote access to greenhouse conditions. This IoT-based approach demonstrates the potential for technology to enhance and modernize greenhouse farming. In this paper, the authors describe a monitoring and controlling system for a greenhouse. The system collects data from various sensors, such as water, humidity, light, and temperature sensors, and sends the information to a base station, which is essentially a microcontroller circuit. The base station then stabilizes the environmental parameters to maintain optimal growing conditions inside the greenhouse. Actuators such as pumps, light bulbs, and fans are used to control the various environmental parameters.

The use of Internet of Things (IoT) technology in greenhouse cultivation has led to significant improvements in microclimate control and data sharing, as well as long-term artificial light source utilization. According to [18], precision technology in advanced greenhouses provides optimal plant growth conditions and increased productivity. Wireless Sensor Networks (WSN) plays a crucial role in these systems, enabling real-time monitoring of climate conditions and remote control. Commercial greenhouses now integrate communication devices, mobile applications, and decision support systems, leading to improved crop condition optimization and predictive capabilities. The paper discusses the importance of microclimate control in greenhouse cultivation and the use of sensor nodes for data collection. To create the perfect environment for plant growth, the microcontroller system regulates temperature, humidity, and light intensity within the greenhouse. Precision irrigation and temperature-humidity control are common techniques utilized in greenhouse cultivation, and the sensor nodes are used to measure moisture levels in the soil for a consistent watering process. The dynamic monitoring system is used to measure the environment conditions and synchronize the approaches to

maintain the greenhouse microclimate. The Internet of Things has significantly improved management systems in greenhouses, but challenges arise when network connections vary in strength, affecting the accuracy of information and system response time. However, according to a study by [19], the Internet of Things in Greenhouse Farming is a viable solution to the food crisis, as it enables the maintenance of optimal environment conditions for plant growth and protection from harsh outdoor conditions.

In a study by [20], a remote monitoring system for greenhouse environment parameters was developed using the NodeMCU ESP 8266 Microcontroller and Blynk Application. Components such as DHT11, light sensor, and TDS sensor were integrated with an Arduino board to collect data and transmit it to a web server for precise monitoring. The system aimed to replace manual monitoring and enable more efficient control of the greenhouse environment. Similarly, [21] presents a study on dynamic monitoring and remote control in a greenhouse using the ESP8266 NodeMCU as the central unit. The system allows for real-time monitoring and control of environmental parameters such as temperature, humidity, light intensity, and moisture level using IoT technology. The collected data is sent to the cloud for storage and analysis, and users can remotely control the system through an instruction controller. The Wi-Fi network connection is established using the HTTP protocol with private API keys for data security. Overall, this project demonstrates the potential of IoT technology in improving greenhouse monitoring and management. The paper presents a greenhouse monitoring system that utilizes an Organic-Light Emitting Diode (OLED) module to display real-time parameters. The Android application Blynk enables data visualization on mobile phones via Internet of Things technology. With the NodeMCU, the system continuously sends current measurements to the cloud for remote monitoring and control. The research highlights the importance of modern technology in regulating microclimates for optimal crop growth.

An Environmental Monitoring System is proposed that utilizes the Arduino and Thing-Speak to monitor weather conditions inside a greenhouse. ThingSpeak, an open-source application and Internet of Things platform, stores and displays live data streams in the cloud, allowing for real-time analysis and interpretation. The system is designed to continuously update and transmit data from sensors to ThingSpeak for further analysis and display. In a related project, [22] developed an automatic sprinkler system for greenhouse using an Arduino microcontroller AVR Atmega328 and a soil moisture sensor. The system is connected to the ThingSpeak platform through the Internet of Things (IoT) network for real-time monitoring and control. Users can register for a new account, obtain the channel ID and Application Programming Interfaces (API) keys to access their data on ThingSpeak. Once data is collected, users can analyze it through charts and graphs presented on the platform. This automation technology is widely used for irrigation to simplify the watering process and increase crop yields. Similarly, [23] proposed a design that utilizes ThingSpeak and Arduino to automate the irrigation system in a greenhouse. The goal is to reduce water usage and prevent waste. ThingSpeak creates a channel in the cloud

platform that enables data exchange. Users can access the environment parameters in the green-house by logging into their account using the same credentials they used during registration. ESP8266 is used to establish a Wi-Fi module and link the Graphic User Interface (GUI) to the ThingSpeak database. This allows users to retrieve all the measurement parameters in the greenhouse and visualize the soil moisture values through an Android application on their electronic device.

Agriculture automation using IoT is becoming increasingly popular and the ThingSpeak platform is often used for data aggregation and visualization. As described in [24], [25], Thing-Speak serve as a database for storing and analyzing data collected from greenhouse sensors. In [26], IoT system for greenhouse automation is presented, employing an Arduino Mega microcontroller and Wi-Fi module in conjunction with ThingSpeak. This system is divided into a monitoring and control system, with real-time sensor data display and remote-control capabilities via ThingSpeak. It effectively monitors and controls various greenhouse parameters, such as temperature, soil moisture, and light intensity, using sensors and relays to trigger actions based on sensor readings. On the wildlife protection front, the study in [27] introduces the Smart Laser Fence, a non-harmful method to deter animals from protected areas using laser beams. This innovation is considered safer and more practical compared to traditional methods like chili and electric fences.

The IOT Based Security System (IBSSS) discussed in [28] supports the implementation of a laser fence as a protective boundary. The laser fence is designed to detect the presence of wild animals by using laser beams and PIR sensors placed on the opposite side of the laser source. When the connection between the laser and PIR sensor is broken, an alarming system activates. Additionally, the system includes an automatically targeted laser gun that points in the direction of the intrusion present. The laser gun uses an ultrasonic sensor fixed on a servo motor to detect the position of the intruder and fires accordingly. According to [29], an intelligent surveillance security system has been developed using a laser fence with GSM communication. The system is energy efficient, utilizing a laser beam, LDR, and mirrors to save costs. Total internal reflection of light is employed by placing two parallel mirrors and receiving incident light from the laser, creating a sub-layer with a zigzag shape. The system also features an image monitoring camera and a GSM module for network communication, notifying the user when an intrusion occurs.

The implementation of a junction box as a protection measure against wild animal intrusion is discussed in [30], [31]. An intelligent agriculture system, using the XBee networking system, is proposed to prevent crop damage. The system utilizes four laser sources placed at different angles and paired with LDR sensors, with each junction box containing a laser gun and LDR sensor. Additionally, precision agriculture techniques are employed, utilizing a smart sensor system to monitor environmental conditions and a watering system, with data transmission facilitated by a GSM module. A junction box is developed for crop field protection, utilizing a virtual fence made of laser and LDR sensors. The system uses GSM communication to send alerts to users in case of intrusion. Each

junction box contains an Arduino microcontroller, RTC, XBee communication system, laser transmitter, and LDR sensor. The RTC is used to record the time of intrusion and send it through the XBee. The virtual fence is constructed by aligning the laser and LDR sensors across different junction boxes. In [32], introduces a wireless sensor network for crop protection against animal intrusion, featuring laser emitters, PIR sensors, XBee, and an Arduino MEGA microcontroller. The system utilizes automatic intrusion detection and aims to maintain ecological balance while deterring animals from crop fields through non-harmful means.

## III. PROPOSED METHOD

In this section, we present our innovative smart greenhouse system with integrated crop protection. The flowchart illustrates the transceiver module workflow. Our advanced microclimate control involves long-distance monitoring, system configuration, and crop condition prediction via Wi-Fi connectivity. The ESP8266 acts as both transmitter and receiver, enabling real-time monitoring and remote control via the Blynk Android app. Additionally, environmental and intrusion data are continuously transmitted to the cloud for future analysis and investigation. All the environmental parameters are adjustable with the help of electronics devices to perform the prefect environmental condition for maximize the crop production. Besides, the laser fence will detect and respond when the intrusion happens. Blynk end users enable to constantly tracking the live stream parameters, receiving the intrusion notification also perform the decision making on system. The block diagram of automation greenhouse is shown in Fig. 1.
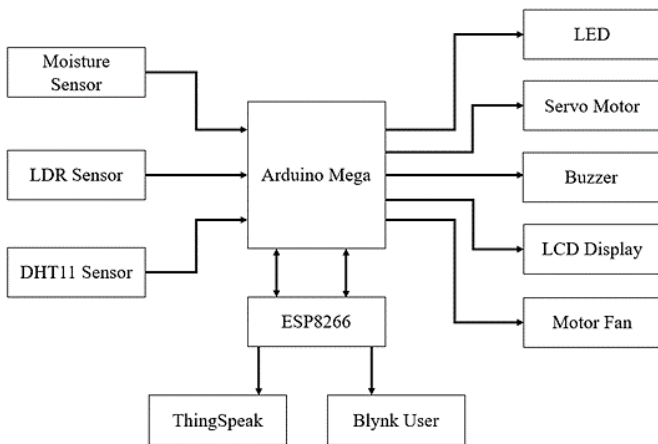


Fig. 1. Block diagram of remote monitoring greenhouse system.

The proposed system follows a structured workflow, as depicted in Fig. 1 and Fig. 2. Fig. 1 outlines the workflow for the transceiver module, which serves as a central component of the system designed for greenhouse monitoring and control. To achieve this, a network of sensors is strategically positioned within the greenhouse. These sensors include moisture sensors for soil moisture measurement, DHT11 sensors for temperature and humidity monitoring, and LDR sensors for assessing light intensity. The data gathered by these sensors is transmitted to an Arduino Mega microcontroller, which assumes the role of data processing and decision-making. Based on the collected

data, the Arduino Mega implements various solutions. For security purposes, the LDR module detects intrusions at two levels, with the red LED and buzzer activated for the first level, and the yellow LED and buzzer for the second level. The NodeMCU transceiver module enables Wi-Fi connectivity, allowing the Arduino Mega to transmit real-time data and notifications to end-users via the Blynk platform. Simultaneously, all greenhouse parameters are sent to the ThingSpeak cloud platform for aggregation over time, enabling graphical visualization and comprehensive data analysis.

The flowchart shows in Fig. 2 states the developed smart greenhouse with crop protection mechanism. In greenhouse, ventilation system functions as balancing the temperature and humidity while the moisture sensor will acts as measure also estimate the water amount in soil. Laser fence will classify the intrusion level then the intrusion prevention system will activate once the intrusion event approaches. All the environmental parameters and intrusion notification enable to view from end user by Blynk application. The details for this architecture will explained on section below.
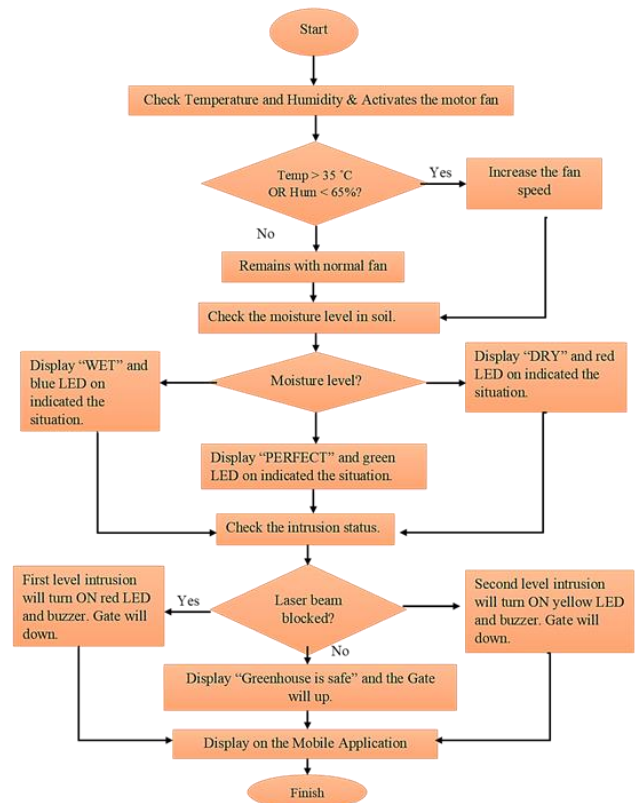


Fig. 2. Flowchart for greenhouse horticulture automation with crops protection.

Upon conducting repeated tests, the initial circuit for the greenhouse has been assembled and is presented in Fig. 3, depicting the connections between the Arduino Mega, NodeMCU ESP8266, sensor devices, and actuators. The TX pin of NodeMCU is connected to the RX pin for Arduino Mega and TX pin of Arduino Mega is connected to the RX pin of NodeMCU so it will establish the serial communication which allows data exchange between these two devices.
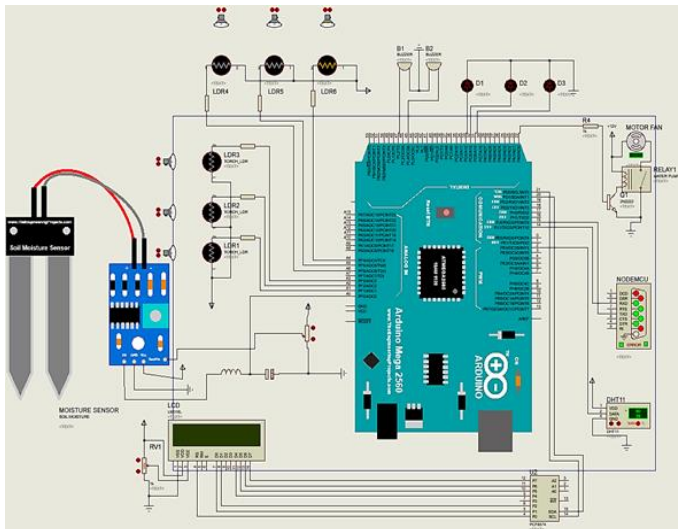
Fig. 3.   Circuit design for greenhouse horticulture automation with crops protection.

## IV.   Result and Discussion

An effective automated greenhouse must meet several essential criteria, such as providing an optimal environment for crop growth, accommodating every stage of plant development, increasing yield quantity, reducing costs, and ensuring crop safety at all times. This section will describe the development of an automated greenhouse that incorporates a laser fence mechanism. The integration of sensors and actuators will also be discussed in the following section.

### A.  Hardware Implementation

The purposed automation greenhouse system functions as constantly environmental parameters up-to-do, climate control system together with crop protection mechanism. Automatic greenhouse always monitoring parameters then activates the actuators device to respond towards the sudden change in the greenhouse. Virtual laser fence mechanism can prevent the hazards from intruder also carried out the high pitch alarming system to chase away the intruder without any physical damaged towards it.

*1) Automation greenhouse with climate control capability*: The researcher employed several hardware components to construct the greenhouse system, such as Arduino Mega, NodeMCU Lua V3 ESP8266 WIFI with CH340C, LDR, LED, Buzzer, DHT11, Soil Moisture sensor, and laser diode, each with their unique function and specifications. The hardware device Arduino Mega is configured to continuously read all the real-time environmental parameters from attached sensor device includes DHT11, LDR sensor also the moisture sensor then converting all inputs into human visual. LCD display will constantly present the current reading like temperature, humidity, light intensity in greenhouse and moisture value of soil in greenhouse. NodeMCU is a powerful IoT development board based on the ESP8266 WiFi module with 128KB RAM and 4MB flash program memory. It features in-built Wi-Fi/Bluetooth, Deep Sleep mode, and CH340 USB converter

for easy installation. With 9 GPIO pins and 1 Analog input pin, NodeMCU is perfect for IoT projects. The DHT11 sensor is a reliable and accurate digital output sensor that uses a digital signal acquisition technique. It has a small size, low power consumption, and easy-to-use four-pin package. It operates on 3.5V to 5.5V with an operation current of 0.3mA. The temperature range is 0°C to 50°C, and the humidity range is 20% to 90%, with 16-bit resolution. The temperature and humidity accuracy are $\pm1˚C$ and $\pm1\%$, respectively, with anti-interference ability and long-distance signal transmission. The moisture sensor measures soil moisture by passing current through the soil via two probes, with the module calculating the water content and providing results as moisture levels. The external probe serves as a variable resistor, modifying its resistance value based on the amount of water present. Both analog and digital outputs are produced. Analog Output (A0) creates the output voltage, while digital Output (D0) digitalizes the resistance value via the LM393 High Precision Comparator on board. Low analog voltage readings indicate higher water content, while high readings indicate lower water content. The laser diode has an electrically isolated case with lead electrical connection and a high reflective index glass lens that produces long-distance beams. It can be controlled by a GPIO pin from the Arduino board and requires power input from 3.3V to 5.0V.

The ventilation system is designed to run continuously to maintain the appropriate temperature and humidity levels for plant growth. The fan speed is controlled by the DC motor's duty cycle, which varies depending on the DHT11's readings. If the temperature exceeds 35˚C or the humidity falls below 65%, the fan speed will increase to raise the duty cycle from the normal 55% to 82%. Soil moisture is crucial for healthy plant growth and must be monitored to ensure proper irrigation.

In this moisture detection mechanism, the moisture sensor will detect analog measurement and classify into three status includes wet, dry and prefect. At first, the analog measurement received more than 800 will classify as dry condition where there are lack of water in plantation area. In greenhouse, LCD display will display "Plant is too DRY" and the red LED will be triggered to notified farmer. Then, analog measurement 500 will assigned to wet condition where the planation area had too much of water. LCD display will "Plant is too WET" then blue LED triggered. Lastly, analog measurement between 501 to 799 is the prefect range of moisture value. Prefect soil condition will show the statement "Soil is PREFECT" on LCD together with triggered green LED. After then, artificial light installed become the lighting supplement for entire greenhouse in Fig. 4 and Fig. 5. The installed hardware implemented can be control by user based on Blynk application. End user can interactive with artificial light by widget button on Blynk according to user's decision. All the current greenhouse measurements and widget buttons will be displayed on Blynk Application in Fig. 6.
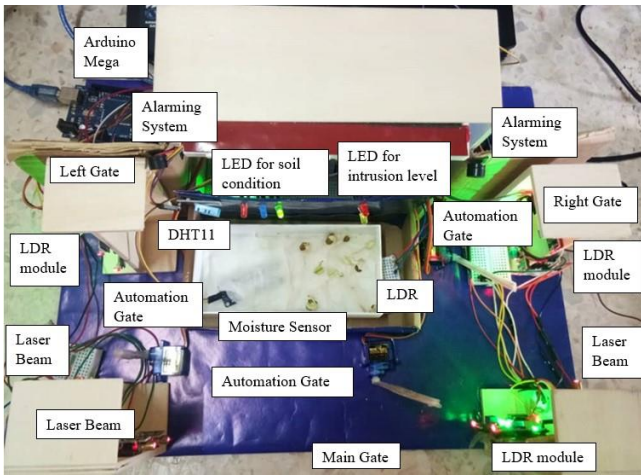
Fig. 4. The prototype of the greenhouse.
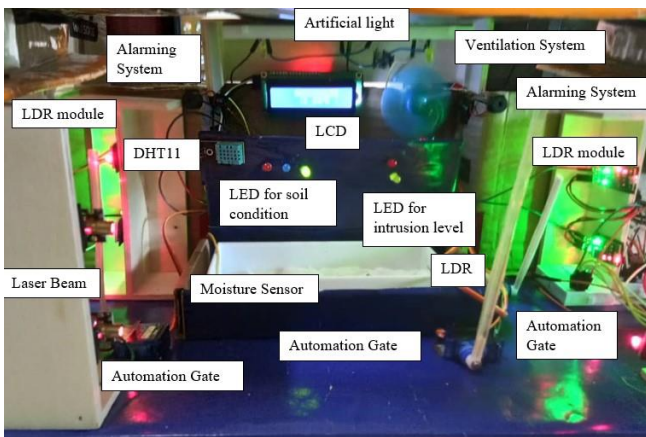


Fig. 5. The front view for greenhouse.
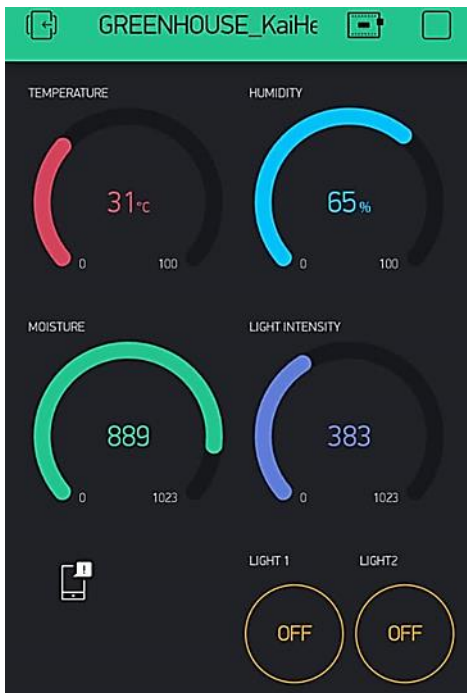


Fig. 6. Current measurement and widget button on blynk application.

## B. Software Implementation

Blynk provides server that connecting managed deployed system also enables remotely take control the internet connected electronic devices with designed widget on interface builder. In the purposed system, end user will constantly view the actual environmental parameters, enables to control artificial light source remotely also receive the intrusion notification details. Then, ThingSpeak allows the instant line graph visualizations for the posted data received. All the parameters received will recorded and displayed into line graph. Line graphs construct the time-series relating between scale object that helps to analyze the trend of read parameters over the time line.



Fig. 7. Data visualization for environmental parameters and intrusion events happens.

*1) Data analysis in thingspeak*: To analyze the data, changes in the temperature, humidity, soil moisture level, and light intensity within the greenhouse are measured over time. In Fig. 7, the selected environmental parameters of the greenhouse are displayed on specific channels on the ThingSpeak cloud service over a certain time period. The intursion event can be interpreted where intrusion status "1" indicates intrusion happens, while "0" means no intrusion. Based on Table I, the average temperature inside the greenhouse is 31 degrees Celsius, while the average humidity level is approximately 73%. Additionally, the average analog measurement for soil moisture is 569, and the light intensity

averages 547. Then, Table II express nterusion events happens on the left, main, right gate. On the figure explained there are two intrusion happen on right gate while no intrusion happen on left and main gate.

TABLE I.    MEASURING AVERAGE PARAMETERS IN A GREENHOUSE ENVIRONMENT

| SELECTED ENVIRONMENT PARAMETER | AVERAGE MEASUREMENT |
|---|---|
| HUMIDITY | 73% |
| LIGHT INTENSITY | 547 |
| TEMPERATURE | 31˚C |
| SOIL MOISTURE | 569 |

TABLE II.    INTRUSION EVENTS HAPPENS IN GREENHOUSE ALONG CERTAIN TIME PERIOD

| LASER FENCE LOCATION | INTRUSION EVENTS |
|---|---|
| LEFT GATE | 0 |
| MAIN GATE | 0 |
| RIGHT GATE | 2 |

*2) Intrusion detection and prevention mechanism*: Intrusion detection fence system built by surround the greenhouse from left, center and right. Each fence consists two pair of laser beam and LDR sensor align up and down that differentiate the intrusion level approaches based on body size of intruder in Fig. 8. At the same time, the alarming system and prevention will be activated also the end users will receive the intrusion notification from Blynk application. Blynk notification will states the information details about the actual location intrusion happens together with intrusion level involved immediately. When an intruder approaches, the system promptly detects their presence and analyses their size shown. Two intrusion levels are defined: the first for large-bodied intruders and the second for smaller ones. The detection is triggered when an intruder obstructs both the up and down laser beams and their respective LDR pairs in Fig. 10. For the first intrusion level is triggered when big body size of intruder step-into and blocked both up and down laser beam and LDR pair installed. Then, second intrusion level is triggered by smaller-bodies intruders as it only managed to block down laser beam LDR pair in greenhouse. Simultaneously, the system communicates with the Blynk application, sending out a detailed intrusion notification. This notification includes vital information about the intrusion event, such as the precise location within the greenhouse and the specific intrusion level involved. Yet, if there are no intrusion happens in greenhouse, LCD display will update the statement "GREENHOUSE IS SAFE!", intrusion prevention will not have activated also Blynk application user will not receive any notification shown in Fig. 9.

*3) A comparison of results obtained on-site and via the blynk application*: In this section, we will be comparing the results obtained on-site with those obtained via the Blynk Application at the same time. The LDR sensor is utilized to

measure any intrusion events, and the NodeMCU is responsible for transmitting the intrusion event to the Blynk Application. The application displays the notification details regarding the level and location of the intrusion. Three scenarios were tested to determine whether they can trigger notifications on the Blynk mobile application simultaneously. Referring to Fig. 11, it is observed that no intrusion event occurred in the greenhouse, and consequently, no notification was displayed on the Blynk application. Fig. 12 and Fig. 13 illustrate that intrusions occurred in the greenhouse. However, in the second test, the first level of intrusion was detected, and in the third test, the second level of intrusion was detected. Table III describes the intrusion events that occurred and the corresponding Blynk application notifications. Then, Table IV shows the status of the automation gate along with the occurrence of intrusion events. Therefore, the comparison between the on-site intrusion events and the notification results on the Blynk Application display accurate and real-time information about the intrusion events that occur.



Fig. 8.    The position of the laser fence at the left, main, and right gate.



Fig. 9.    The display statement that no intrusion happen in greenhouse.
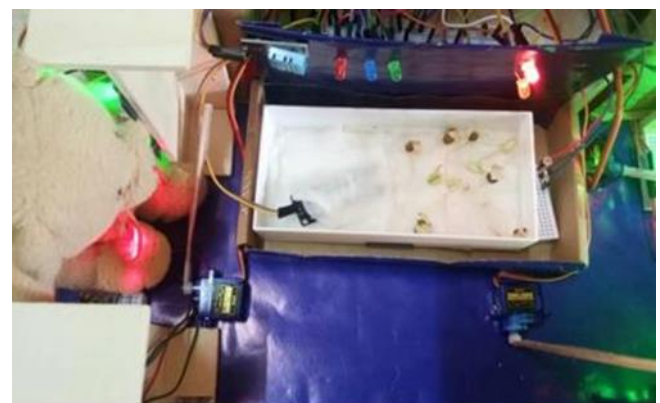


Fig. 10.  The approach of a large intruder towards the left gate.
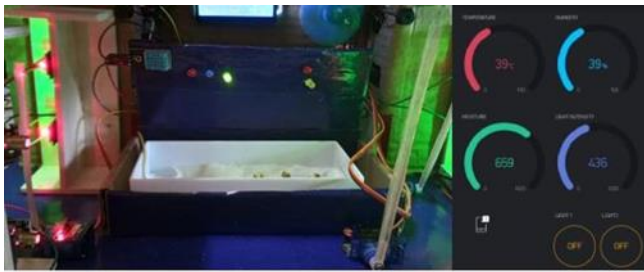
Fig. 11. First test in main gate.
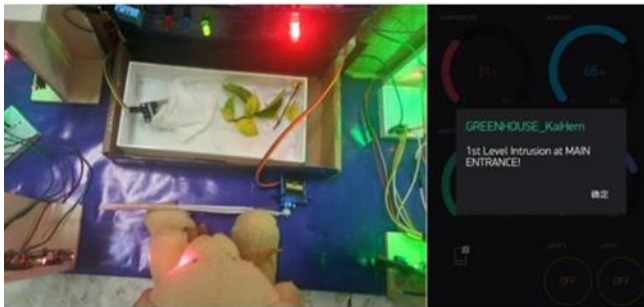


Fig. 12. Second test in main gate.
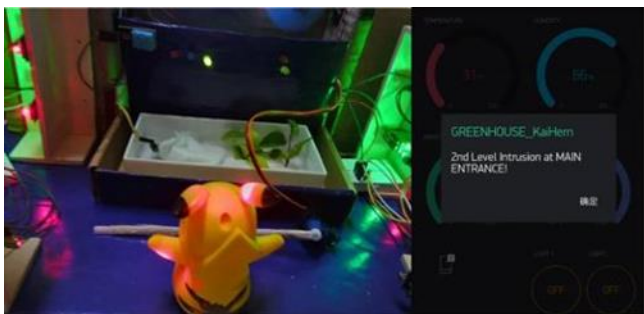


Fig. 13. Third test in main gate.

TABLE III. COMPARISON RESULT BASED ON INTRUSION EVENT AND BLYNK APPLICATION DISPLAYED

| LASER FENCE AT MAIN GATE | SITUATION | | NOTIFICATION DETAILS DISPLAYED ON BLYNK APPLICATION |
|---|---|---|---|
| | FIRST INTRUSION LEVEL | SECOND INTRUSION LEVEL | |
| FIRST TEST | NO | NO | NO |
| SECOND TEST | YES | NO | YES |
| THIRD TEST | NO | YES | YES |

TABLE IV. COMPARISON RESULT BASED ON INTRUSION EVENT AND AUTOMATION GATE STATUS

| LASER FENCE AT MAIN GATE | SITUATION | | AUTOMATION GATE TURNING DOWN |
|---|---|---|---|
| | FIRST INTRUSION LEVEL | SECOND INTRUSION LEVEL | |
| FIRST TEST | NO | NO | NO |
| SECOND TEST | YES | NO | YES |
| THIRD TEST | NO | YES | YES |

*4) Comparison with internet speed and performance of automation greenhouse*: In this section, the performance of the greenhouse system will be evaluated. The time taken for the system to respond was observed by comparing the internet

speed and NodeMCU's time response to receive an instruction. Internet speeds of 10.1 Mbps, 20.0 Mbps, 45.7 Mbps, and 98.9 Mbps were selected for this testing section shown in Fig. 14.



Fig. 14. Results of internet speed testing.
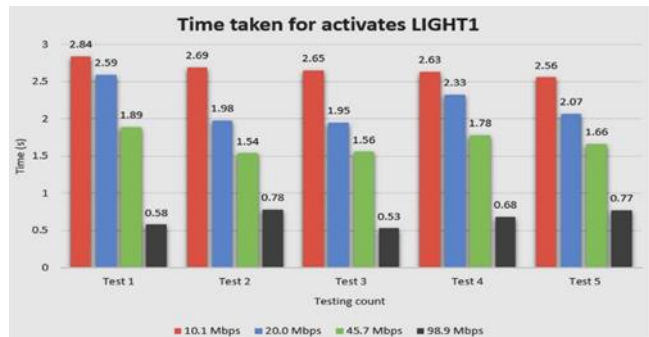


Fig. 15. The time taken for activates LIGHT1.
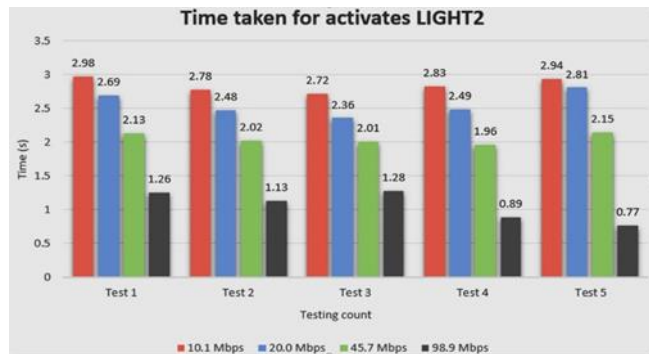


Fig. 16. The time taken for activates LIGHT2.
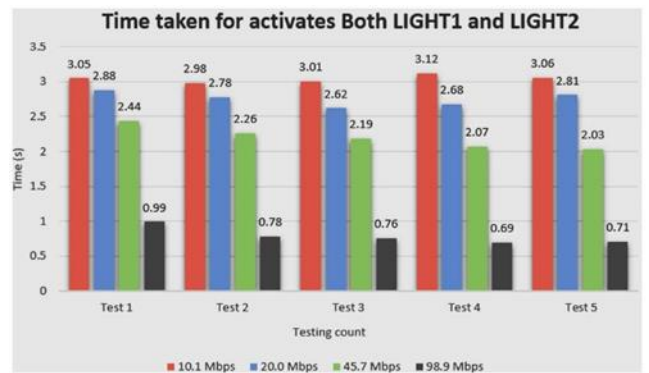


Fig. 17. The time taken for activates both LIGHT1 and LIGHT2.

TABLE V. AVERAGE ACTIVATION TIME FOR LIGHT1

| INTERNET SPEED (MBPS) | AVERAGE TIME RESPONSE (S) |
|---|---|
| 10.1 | 2.67 |
| 20.0 | 2.18 |
| 45.7 | 1.69 |
| 98.9 | 0.67 |

TABLE VI. AVERAGE ACTIVATION TIME FOR LIGHT2

| INTERNET SPEED (MBPS) | AVERAGE TIME RESPONSE (S) |
|---|---|
| 10.1 | 2.85 |
| 20.0 | 2.57 |
| 45.7 | 2.10 |
| 98.9 | 1.10 |

TABLE VII. AVERAGE ACTIVATION TIME FOR BOTH LIGHT1 AND LIGHT2

| INTERNET SPEED (MBPS) | AVERAGE TIME RESPONSE (S) |
|---|---|
| 10.1 | 3.04 |
| 20.0 | 2.75 |
| 45.7 | 2.20 |
| 98.9 | 0.79 |

Fig. 15, 16, and 17 depict the response time of the NodeMCU to receive a signal in relation to the internet speed. Five tests were conducted under three different scenarios, each with varying internet speeds. After analyzing the results, the average response time for different internet speeds, including 10.1 Mbps, 20.0 Mbps, 42.7 Mbps, and 98.9 Mbps, was calculated and recorded in Tables V, VI, and VII based on the respective event situations. Table V presents the average response time required to activate only LIGHT1, with the highest response time recorded at 10.1 Mbps internet speed, which took 2.67 seconds. The next highest response time was recorded at 20.0 Mbps, taking 2.18 seconds, followed by 45.7 Mbps at 1.69 seconds. The lowest response time was recorded at 98.9 Mbps, which took only 0.67 seconds. Then, Table VIdisplays the average time response, indicating that the shortest response time was observed for internet speed 98.9 Mbps, with 1.01 seconds, followed by internet speed 10.1 Mbps with 2.85 seconds, internet speed 20.0 Mbps with 2.57 seconds, and internet speed 45.7 Mbps with 2.10 seconds. Other than that, Table VII displays the average time required to activate both LIGHT1 and LIGHT2. The shortest time taken was observed with an internet speed of 98.9 Mbps, which was 0.79 seconds. This was followed by 10.1 Mbps, which took 3.04 seconds, internet speed 20.0 Mbps, which took 2.75 seconds, and internet speed 45.7 Mbps, which took 2.20 seconds. Thus, the finding in graphs and table provides evidence that the higher of internet speed the shorter time taken to response.

## V. CONCLUSIONS

The greenhouse automation with crops protection prototype underwent both hardware and software testing to ensure its proper implementation. The hardware component was used to measure and provide information about environmental parameters and intrusion notifications to enhance plant growth and improve crop security. The Blynk mobile application served as an interface for users, while ThingSpeak acted as the cloud database that collected and displayed all the recorded data over time. The automated greenhouse is designed to mimic the real-time conditions of a greenhouse by maintaining suitable environmental conditions automatically. Users can remotely view, control, and receive intrusion alerts via the Blynk Application. The protection system for this automated greenhouse includes a laser fence, an alarming system, and an automated gate. The laser fence is used to detect any unauthorized encounters and estimate the body size and level of danger of approaching objects. Upon detection of intrusion events, the alarming system buzzer will be activated and the automation gate will be automatically closed. The triggered alarm serves to deter intruders and notify the relevant authorities of the threat of intrusion. The automation gate, when closed, protects the crops from damage or theft by unauthorized persons. Once intrusion event happens, the Blynk end user will immediately receive the intrusion notification with details like intrusion event location together with intrusion level involved.

Furthermore, the analysis of the weather condition in the automation greenhouse was conducted, and the average results were tabulated. Additionally, the performance of the greenhouse was tested by comparing the average time taken at different internet speeds. As fast internet speed, al-lows the actuators to perform quickly respond onto the unexpected change in greenhouse. However, there remains a research gap related to the long-term performance and reliability of the system. Future studies should explore the system's performance over multiple growing seasons to assess its durability, adaptability to changing environmental conditions, and overall reliability in real-world agricultural settings. The results indicate that higher internet speeds lead to shorter response times and increased accuracy. Additionally, the accuracy of the laser fence was investigated, and it was found that the notifications displayed on the Blynk application were exactly the same as the on-site situation. Blynk end user straight away received current intrusion event together with intrusion information details regardless of location or time periods. At the end, all objectives of this purposed system had achieved successfully. Researcher enable to prove previous discussed research paper which mention automation greenhouse enable to solve traditional farming issues, enhancing the quality and quantity of crops which simulate the sales practically. As well, laser fence mechanism is the best choice in term of cost-efficiency, generate incomes also humane.

The proposed automation system for greenhouses with crop protection holds immense potential for commercialization within the agricultural and floral industries. In an era where these sectors are under increasing pressure to deliver high yields and exceptional quality, this innovative solution offers a multitude of benefits. Firstly, it promises to significantly boost production by optimizing critical growth conditions, including temperature, humidity, and lighting. This enhanced control not only results in higher crop yields but also ensures the consistency and quality demanded by these industries. Additionally, the system contributes to cost savings, as it minimizes labor requirements and reduces resource wastage. Moreover, it mitigates the need for excessive pesticide and chemical treatments, not only saving on costs but also aligning with environmentally sustainable practices. Ultimately, the primary goal of this proposed work is to maximize crop productivity while increasing the income of the agriculture industry, making it an enticing prospect for commercialization.

ACKNOWLEDGMENT

REFERENCES

[1] S. N. S. Al-Humairi, P. Manimaran, M. I. Abdullah, and J. Daud, "A Smart Automated Greenhouse: Soil Moisture, Temperature Monitoring and Automatic Water Supply System (Peaty, Loam and Silty)," 2019 IEEE Conf. Sustain. Util. Dev. Eng. Technol. CSUDET 2019, pp. 111–115, 2019, doi: 10.1109/CSUDET47057.2019.9214661.

[2] S. Alyousif, N. F. Zainuddin and B. B. Hamzah, "Intelligent Temperature Control System at Greenhouse", International Journal of Applied Engineering Research, vol. 12, no. 9, pp. 1811-1814, 2017.

[3] R. Deekshath, P. Dharanya, K. R. D. Kabadia, G. D. Dinakaran, and S. Shanthini, "IoT Based Environmental Monitoring System using Arduino UNO and Thingspeak," Int. J. Sci. Technol. Eng. |, vol. 4, no. 9, pp. 68–75, 2018.

[4] M. H. Farhangi, M. E. Turvani, A. van der Valk, and G. J. Carsjens, High-tech urban agriculture in Amsterdam: An actor network analysis, vol. 12, no. 10. 2020.

[5] V. R. Nyirenda, B. A. Nkhata, O. Tembo and S. Siamundele, "Elephant crop damage: Subsistence farmers' social vulnerability livelihood sustainability and elephant conservation", Sustainability, vol. 10, no. 10, pp. 1-19, 2018.

[6] W. M. Abdelhakim, "Scaring Birds: The concept of the Scarecrow in Ancient Egypt," Int. J. Heritage, Tour. Hosp., vol. 33, no. 4, pp. 42–51, 2019.

[7] S. Yadahalli, A. Parmar, and A. Deshpande, "Smart Intrusion Detection System for Crop Protection by using Arduino," Proc. 2nd Int. Conf. Inven. Res. Comput. Appl. ICIRCA 2020, pp. 405–408, 2020, doi: 10.1109/ICIRCA48905.2020.9182868.

[8] S. F. A. Gani, R. A. Hamzah, R. Latip, S. Salam, F. Noraqillah and A. I. Herman, "Image compression using singular value decomposition by extracting red, green, and blue channel colors," in Bulletin of Electrical Engineering and Informatics, vol. 11, no. 1, pp. 168-175, 2022. doi: 10.11591/eei.v11i1.2602.

[9] S. Ngama, L. Korte, J. Bindelle, C. Vermeulen and J. R. Poulsen, "How bees deter elephants: Bee-hive trials with forest elephants (loxodonta africana cyclotis) in Gabon", PLoS ONE, vol. 11, no. 5, pp. 1-12, 2016.

[10] I. Nanda, S. Chadalavada, M. Swathi, and L. Khatua, "Implementation of IoT based smart crop protection and irrigation system," J. Phys. Conf. Ser., vol. 1804, no. 1, 2021, doi: 10.1088/1742-6596/1804/1/012206.

[11] S. J. Soheli, N. Jahan, M. B. Hossain, et al., "Smart Greenhouse Monitoring System Using Internet of Things and Artificial Intelligence," Wireless Pers. Commun., vol. 124, pp. 3603-3634, 2022. DOI: 10.1007/s11277-022-09528-x.

[12] C. Bersani, C. Ruggiero, R. Sacile, A. Soussi, and E. Zero, "Internet of Things Approaches for Monitoring and Control of Smart Greenhouses in Industry 4.0," Energies, vol. 15, no. 10, p. 3834, May 2022, doi: 10.3390/en15103834.

[13] R. A. Hamzah, A. F. Kadmin, S. F. A. Gani, K. A. Aziz, T. M. F. T. Wook, N. Mohamood and M. G. Y. Wei, "A study of edge preserving filters in image matching," in Bulletin of Electrical Engineering and Informatics, vol. 10, no. 1, pp. 111-117, 2021. doi: 10.11591/eei.v10i1.1947.

[14] T. Saha et al., "Construction and Development of an Automated Greenhouse System Using Arduino Uno," Int. J. Inf. Eng. Electron. Bus., vol. 9, no. 3, pp. 1–8, 2017, doi: 10.5815/ijieeb.2017.03.01.

[15] I. Prasojo, P. T. Nguyen, O. Tanane, and N. Shahu, "Design of Ultrasonic Sensor and Ultraviolet Sensor Implemented on a Fire Fighter Robot Using AT89S52," J. Robot. Control, vol. 1, no. 2, pp. 55–58, 2020, doi: 10.18196/jrc.1212.

[16] A. HASSAN, W. Shah, … N. H.-… J. of H., and undefined 2019, "The Development of an Automated Irrigation System Using an Open Source Microcontroller," Journal.Utem.Edu.My, vol. 3, no. 1, 2019.

[17] V. E. Balas Vijender, K. Solanki, R. Kumar, M. Atiqur, and R. Ahad, Intelligent Systems Reference Library 165 A Handbook of Internet of Things in Biomedical and Cyber Physical System. Springer, Cham, 2021.

[18] R. R. Shamshiri et al., "Advances in greenhouse automation and controlled environment agriculture: A transition to plant factories and urban agriculture," Int. J. Agric. Biol. Eng., vol. 11, no. 1, pp. 1–22, 2018, doi: 10.25165/j.ijabe.20181101.3210.

[19] R. Rayhana, G. Xiao, and Z. Liu, "Internet of Things Empowered Smart Greenhouse Farming," IEEE J. Radio Freq. Identif., vol. 4, no. 3, pp. 195–211, 2020, doi: 10.1109/jrfid.2020.2984391.

[20] Y. Astutik, Murad, G. M. D. Putra, and D. A. Setiawati, "Remote monitoring systems in greenhouse based on NodeMCU ESP8266 microcontroller and Android," AIP Conf. Proc., vol. 2199, no. December, 2019, doi: 10.1063/1.5141286.

[21] Z. Wan, Y. Song, and Z. Cao, "Environment dynamic monitoring and remote control of greenhouse with ESP8266 NodeMCU," Proc. 2019 IEEE 3rd Inf. Technol. Networking, Electron. Autom. Control Conf. ITNEC 2019, no. Itnec, pp. 377–382, 2019, doi: 10.1109/ITNEC.2019.8729519.

[22] I. S. Nasution, M. R. Iskandar, and D. S. Jayanti, "Internet of Things: Automatic Sprinklers in Prototyping Greenhouse Using Smartphone Based Android," in IOP Conference Series: Earth and Environmental Science, vol. 425, no. 1, 2020, p. 012069, doi: 10.1088/1755-1315/425/1/012069.

[23] H. BENYEZZA, M. BOUHEDDA, K. DJELLOUT, and A. SAIDI, "Smart Irrigation System Based ThingSpeak and Arduino," no. November, pp. 2018–2021, 2018.

[24] K. Ganesh and K. N. Rao, "Autonomous Greenhouse using Internet of Things with ThingSpeak," pp. 95–99, 2019.

[25] S. F. A. Gani, M. F. Miskon and R. A. Hamzah, "Depth Map Information from Stereo Image Pairs using Deep Learning and Bilateral Filter for Machine Vision Application," 2022 IEEE 5th International Symposium in Robotics and Manufacturing Automation (ROMA), Malacca, Malaysia, 2022, pp. 1-6, doi: 10.1109/ROMA55875.2022.9915680.

[26] N. N. Y. Sang and N. K. Hlaing, "Smart Greenhouse using ThingSpeak IoT Platform," J. Comput. Appl. Res., vol. 1, no. 1, pp. 141–145, 2020.

[27] M. F. M. Firdhous, "IoT-enhanced Smart Laser Fence for Reducing Human Elephant Conflicts," Proc. ICITR 2020 - 5th Int. Conf. Inf. Technol. Res. Towar. New Digit. Enlight., 2020, doi: 10.1109/ICITR51448.2020.9310854.

[28] V. Goel, V. Chauhan, R. C. Jha, and S. Pandey, "IoT based smart security system:IBSSS," Proc. 2019 6th Int. Conf. Comput. Sustain. Glob. Dev. INDIACom 2019, pp. 303–306, 2019.

[29] R. A. Deshmukh, S. Kamdi, M. Pingle, S. Rajebhosale, and A. Bhosale, "Intelligent surveillance system using energy efficient intrusion detection and tracking techniques," Proc. 2nd Int. Conf. Electron. Commun. Aerosp. Technol. ICECA 2018, no. Iceca, pp. 1214–1218, 2018, doi: 10.1109/ICECA.2018.8474557.

[30] R. K. Megalingam et al., "Design and Implementation of Junction Boxes for Preventing Animal Attacks in Farms," 2020 IEEE Int. Students' Conf. Electr. Electron. Comput. Sci. SCEECS 2020, 2020, doi: 10.1109/SCEECS48394.2020.119.

[31] G. Sushanth and S. Sujatha, "IOT Based Smart Agriculture System", 2018 International Conference on Wireless Communications Signal Processing and Networking (WiSPNET), pp. 1-4, 2018.

[32] V. Bapat, P. Kale, V. Shinde, N. Deshpande, and A. Shaligram, "WSN application for crop protection to divert animal intrusions in the agricultural land," Comput. Electron. Agric., vol. 133, pp. 88–96, 2017, doi: 10.1016/j.compag.2016.12.007.

# Reinforcement Learning-based Answer Selection with Class Imbalance Handling and Efficient Differential Evolution Initialization

Jia Wei

College of Education Science, Bohai University
Jinzhou 121000, Liaoning, China

*Abstract*—Answer selection (AS) involves the task of selecting the best answer from a given list of potential options. Current methods commonly approach the AS problem as a binary classification task, using pairs of positive and negative samples. However, the number of negative samples is usually much larger than the positive ones, resulting in a class imbalance. Training on imbalanced data can negatively impact classifier performance. To address this issue, a novel reinforcement learning-based technique is proposed in this study. In this approach, the AS problem is formulated as a sequence of sequential decisions, where an agent classifies each received instance and receives a reward at each step. To handle the class imbalance, the reward assigned to the majority class is lower than that for the minority class. The parameters of the policy are initialized using an improved Differential Evolution (DE) technique. To enhance the efficiency of the DE algorithm, a novel cluster-based mutation operator is introduced. This operator utilizes the K-means clustering approach to identify the winning cluster and employs an upgrade strategy to incorporate potentially viable solutions into the existing population. For word embedding, the DistilBERT model is utilized, which reduces the size of the BERT (Bidirectional encoder representations from transformers) model by 40% and improves computational efficiency by running 60% faster. Despite the decrease, the DistilBERT model maintains 97% of its language comprehension abilities by utilizing knowledge distillation in the pretraining phase. Extensive experiments are carried out on LegalQA, TrecQA, and WikiQA datasets to assess the suggested model. The outcomes showcase the superiority of the proposed model over existing techniques in the domain of AS.

*Keywords*—*Answer selection; imbalanced classification; reinforcement learning; DistilBERT; differential evolution*

## I. INTRODUCTION

Question Answering (QA) systems, a notable application within natural language processing (NLP) and artificial intelligence (AI), facilitate enhanced human-computer interaction by efficiently processing expansive data and information. Two dominant strategies for developing QA systems include the deployment of Generative Adversarial Networks (GANs) [1] and the utilization of AS techniques. While GANs can generate rich and varied responses, their application comes with challenges related to ensuring grammatical and semantic accuracy in answers. In contrast, AS focuses on meticulously selecting the most apt response from a set of potential answers to a given query, taking into account

the inherent variability and complexity of language and potential multiple suitable responses, thereby finding extensive application in various domains including machine comprehension [2]. Both methodologies bring their respective benefits and limitations, influencing their applicability in different use-cases within the broader QA landscape.

Conventional and deep learning techniques offer various methods for AS according to existing literature [3]. While traditional models, like those based on information retrieval, handcrafted rules [4], and machine learning (ML) methods [5] provide certain utilities, they also exhibit limitations in semantic understanding and generalization due to reliance on keywords, manual features, or rigid rules. SVM classifiers within ML approaches have been utilized to connect AS pairs through editing distance and implied matches, yet traditional ML methods often neglect semantic data and demonstrate confined generalizing capacity. Deep learning methods leverage LSTM or CNN architectures to extract semantic features, utilizing their ability to gauge semantic similarity between questions and answers [6]. CNNs model hierarchical sentence structures, while LSTMs ensure representations contain coherent and pertinent information [7]. Notwithstanding their advancements, deep learning models still face challenges in encapsulating comprehensive semantic relationships between questions and answers. To address this, new models, like BERT, harness next-word/phrase prediction and masked word prediction to assimilate complex linguistic relations, outperforming previous models and widely impacting the NLP field [8].

The success of deep algorithms relies heavily on factors like architecture, learning method, and training features, making network design a sophisticated optimization task. Various researchers [9] have addressed this by training neural networks with fixed topologies using several optimization approaches, such as tabu search, ant colony optimization, genetic algorithm, and simulated annealing [10]. Critical to deep models' performance is the optimization of parameter sets, heavily influenced by their initialization [11]. While gradient descent algorithms like Backpropagation (BP) and Levenberg-Marquardt (LM) [12] have been utilized for weight optimization in deep learning methods for AS, their sensitivity to initial weights may lead to local optimum issues. Addressing this, Pretraining weights using Population-based Meta-Heuristic algorithms (PBMH) [13], [14] like DE [15], which incorporates mutation, crossover, and selection steps, has

proven effective for optimizing learning processes by avoiding local minima and ensuring generation of potentially promising solutions [16], [17].

Furthermore, while BERT has established its dominance in NLP tasks due to its deep architecture and ability to capture bidirectional contexts in textual data, its complexity often renders it computationally expensive, especially for real-time applications. Recognizing this challenge, researchers introduced DistilBERT, a distilled version of BERT. The principle behind DistilBERT lies in the concept of knowledge distillation. This technique involves training a smaller model, in this case, DistilBERT, to mimic the behavior and performance of its larger counterpart, BERT. By transferring the knowledge from the cumbersome BERT model to the more lightweight DistilBERT, there is a significant reduction in model size—about 40% smaller than BERT [18]. Notably, despite this reduction, DistilBERT retains a substantial portion of BERT's language comprehension capabilities, making it an efficient alternative for applications demanding both speed and accuracy.

The proposed AS methods utilize binary classifications defined in positive-negative pairs, presenting challenges due to data imbalances as the positive class tends to be smaller than the negative class. This imbalance can degrade model performance but can be addressed through data-level and algorithm-level approaches. Data-level strategies manipulate training data distribution via over/under-sampling of classes, using methods like Synthetic Minority Over-sampling Technique (SMOTE) [19] for creating new samples, and Near Miss [20] for under-sampling by randomly removing samples from the larger class. While under-sampling can omit valuable data, over-sampling might increase over-fitting risk. Algorithmic-level strategies emphasize minority classes through ensemble learning, decision threshold changes, and cost-sensitive learning, which penalizes misclassification of minority class samples. Ensemble learning, in particular, leverages majority voting among multiple classifiers. Additionally, Deep RL has shown promise in various [21] and can manage data imbalance by assigning higher rewards to minority classes in its reward functions [22].

In the realm of AI-driven AS, a pertinent inquiry often raised revolves around the possibility of artificial intelligence (AI) providing a singular, definitive answer. Traditional AS models, by design, sift through potential options to select the most fitting response. However, the rapidly evolving nature of AI and its profound capabilities in understanding intricate data patterns pose a thought-provoking question: can a sophisticated model predict just one conclusive answer, thereby eliminating the need for answer selection? In such a scenario, the fundamental nature of AS would undergo a paradigm shift. The model presented in this paper, with its intricate interplay of RL, DistilBERT word embedding, and enhanced DE, is primarily designed to make the most informed choice from a range of potential answers. While our model showcases efficacy in the AS paradigm, it's worth considering its adaptability in a landscape where AI's aim shifts towards forecasting a singular, precise answer. This perspective not only paves the way for further enhancements to the existing AS models but also encourages a rethinking of AI role in QA systems.

The work introduces an AS model that integrates RL, DistilBERT word embedding, and an enhanced DE method. The model employs two attention-mechanism-based LSTM networks and a feed-forward network, focusing on learning both positive and negative question-answer pairs, utilizing DistilBERT for semantic matching without pre-engineered features. An improved DE algorithm navigates the search space to apply BP algorithms in LSTMs and feed-forward networks, using a selective mutation operator and a novel updating strategy to generate candidate solutions. RL addresses data imbalance in the BP step by treating as a sequential decision-making process. The agent uses environment states for training examples to classify and earn rewards based on correct/incorrect classifications, favoring minority groups in the reward system. The efficacy of the method is demonstrated on three benchmark datasets: TrecQA, LegalQA, and WikiQA, showing superiority over existing models.

Our primary contributions are as follows:

- The adoption of DistilBERT, the state-of-the-art language representation model, for the purpose of attaining sophisticated word embedding, which aims to enrich the semantic understanding of financial texts.

- The introduction of a novel model grounded in RL designed specifically to navigate and mitigate the challenges presented by data imbalance, thereby enhancing the reliability and robustness of the analysis.

- The deployment of an advanced DE algorithm for the crucial task of weight initialization, which is anticipated to augment the predictive accuracy and computational efficiency of the proposed model.

The remaining sections of this article are organized as follows. In Section II, a summary of the relevant work is provided; in Section III, the required background is presented; in Section IV, the structure of the proposed model is described; and in Section V, evaluation metrics, data sets, and results are provided. In Section VI, the study concludes by detailing the lessons learnt and suggesting further work.

## II. RELATED WORK

The early studies on AS marked the initial attempts to tackle the task using feature engineering techniques. These methods, such as counting common words, Bag-of-phrases, and Bag-of-grams, provided a basic understanding of the structure and content of questions and answers [23]. However, their reliance on surface-level features limited their ability to capture the deeper semantic nuances inherent in natural language. Recognizing the need to overcome this limitation, subsequent research endeavors delved into more sophisticated approaches for AS. Linguistic tools like WordNet emerged as valuable resources for incorporating semantic knowledge into the selection process [24]. WordNet enabled researchers to enrich the analysis of questions and answers by considering the meanings and associations conveyed by individual words.

Furthermore, researchers sought to exploit the syntactic structure of sentences to enhance AS performance. Techniques like dependency tree analysis and tree distance processing algorithms were employed to capture the relationships between

words and their syntactic roles within a sentence. By considering the hierarchical structure and dependencies encoded in these linguistic representations, researchers aimed to gain deeper insights into the meaning and coherence of questions and answers, enabling more effective selection algorithms. The incorporation of semantic and syntactic analysis in AS research represented a significant shift towards a more comprehensive understanding of language. These approaches recognized that the success of answer selection lies not only in surface-level matching but also in capturing the underlying meaning and context conveyed by questions and answers. As a result, the field witnessed the emergence of more sophisticated methods that combined linguistic tools, syntactic analysis, and semantic knowledge to improve the accuracy and relevance of answer selection algorithms.

In recent years, deep learning models have emerged as powerful tools for AS, leveraging automated feature extraction capabilities to improve performance and enhance the understanding of question-answer pairs [25], [26]. When searching using question-answer pairs, researchers have explored two main approaches. The first approach involves calculating distinct elements in the Q&A pair, with deep networks generating independent representation vectors for questions and answers. To measure the interdependence between these vectors, various criteria have been employed, enabling the comparison and similarity assessment of question-answer pairs [25], [26]. For instance, Wang and Jiang proposed a comparative model that incorporates multiple indicators to measure similarity, taking into account different aspects of the question-answer relationship [25]. Similarly, Yun et al. showcased the advantages of language-based models, utilizing the language model Elmo to capture contextual information and semantic meaning in the question-answer pairs [26]. The second approach treats the query and answer as standalone sentences, allowing researchers to employ specific techniques for their analysis. Severin and Moschitti utilized CNNs to assess the similarity between question-answer pairs, exploiting the local dependencies and patterns within the sentences [27]. On the other hand, Van and Newberg utilized bidirectional LSTM networks, which consider the embedding of words in both directions to capture the contextual information of the question and answer [28]. The resulting relation between the answer and the question is fed into a feed-forward network for further processing and classification. Siamese Networks have also gained popularity in QA tasks, providing separate representation vectors for questions and answers [29], [30]. These networks enable the comparison of the similarity or dissimilarity between question-answer pairs by computing the distance or similarity metrics in the learned feature space. For instance, Yu et al. proposed a deep learning model for AS tasks, employing CNNs and logistic regression to capture the relevant features for answer selection [29]. Similarly, Dryer et al. implemented a similar approach using CNNs and distributed vector representations, enabling the model to learn more nuanced features for question-and-answer representation [30]. To further enhance candidate response selection, researchers have explored pre-processing operations. One such operation involves fixing named entities with unique tokens, simplifying the selection process and enabling better identification of potentially correct answers [31], [32]. This pre-processing step

can help alleviate the challenges posed by named entities and improve the accuracy of answer selection. In addition to pre-processing, attention mechanisms have emerged as a valuable strategy in AS research. Initially introduced for machine translation, attention methods have found applications in QA tasks [33]–[35]. These mechanisms allow the model to focus on the most relevant parts of the question and answer by considering the contextual interplay between them. Researchers, such as Jan et al., have proposed using Recurrent Neural Networks (RNNs) with attention mechanisms for response selection, effectively capturing the informative parts of the question-answer pairs [33]. Tay et al. suggested bidirectional alignment and a generalized method based on RNNs further to improve the attention mechanism's performance [34]. Additionally, He et al. demonstrated that combining CNNs with attentional mechanisms can lead to improved performance compared to using RNNs alone [35]. Knowledge-based approaches have also been explored, aiming to leverage external knowledge sources to enhance answer selection. Shen et al. developed a knowledge-based approach that utilizes an attentive bidirectional LSTM network combined with a knowledge graph (KG) to represent questions and answers, enabling the model to leverage structured knowledge to enhance the understanding and selection process [36]. Other techniques have addressed specific challenges in AS, such as data imbalance. Researchers have utilized separate LSTM networks for questions and answers, followed by a Multi-Layer Perceptron (MLP) network for classification, and incorporated per-class penalties to tackle data imbalance and improve classification performance [37]. Matsubara et al. utilized a search engine and a transformer model to select the correct answer, employing models like Jaccard Similarity and Compare Aggregate to assess the relevance of question responses [38]. Furthermore, Kim et al. proposed an architecture based on proximity reference, using an attention mechanism to retain information and automatic encoders better to reduce the information volume, enhancing the model's efficiency and effectiveness [39]. The recent advancements in deep learning models for AS have showcased the versatility and power of these approaches in capturing the complex relationships and semantics present in question-answer pairs. By leveraging techniques such as attention mechanisms, linguistic tools, knowledge graphs, and pre-processing operations, researchers have made significant strides in improving AS performance, ultimately enabling more accurate and relevant answer selection.

Despite the advantages of automatic feature extraction in deep models for AS, there are still several challenges that affect their performance. Typically, these models employ random weight initialization and are trained using the backpropagation BP algorithm to avoid local optima. However, they face difficulties in learning binary classification tasks, particularly when dealing with imbalanced datasets in the context of AS.

## III. BACKGROUND

In this section, the prerequisites required to study the rest of the paper are briefly reviewed.

## A. Long Short-Term Memory (LSTM)

The LSTM framework, initially brought forward by Hochreiter and Schmidhuber [40], signifies a category of neural structure specifically formulated to proficiently manage the interrelationships within a chain of elements that don't possess a fixed length. The innovative structural design makes it distinctive from conventional neural structures by integrating a storage component within its concealed layer, granting it the capability to comprehend relationships within chains that extend beyond immediate surroundings. This feature equips LSTMs with a particular competence in modelling and interpreting extended dependencies. At the heart of the LSTM architecture is storage elements designed to retain and modify data over a period. This storage unit is made of three critical constituents, often referred to as controllers: the ingress controller ($i_t$), the oblivion controller ($f_t$), and the egress controller ($o_t$). These controllers manage the stream of data within the LSTM unit, facilitating accurate regulation of what data is conserved, disregarded, and exported. The ingress controller ($i_t$) establishes the extent to which fresh data is incorporated into the storage unit. It considers the present ingress ($x_t$) and the preceding state of the storage unit ($h_{t-1}$), and grounded on their interaction, resolves which data is pertinent to refresh the unit state. The oblivion controller oversees the volume of data preserved in the storage unit from the preceding moment. It assesses the current ingress and the preceding storage unit state and resolves what data should be forgotten or discarded from the unit. The egress controller establishes the volume of data from the storage unit that is passed to the egress and influences the concealed state of the LSTM. The egress controller considers the current ingress and the refreshed storage unit state and decides what data should be communicated as the egress. Through the amalgamation of these controllers, the LSTM network can selectively preserve and refresh data over time, equipping it to comprehend both short-term and extended dependencies within sequences. This ability to comprehend and retain pertinent data at appropriate time steps makes LSTMs remarkably competent in an array of assignments such as linguistic processing, speech recognition, and time series prediction.

Mathematically, the LSTM equations can be defined as follows:

$$i_t = \sigma(W_i x_t + U_i h_{t-1} + b_i) \qquad (1)$$

$$f_t = \sigma(W_f x_t + U_f h_{t-1} + b_f) \qquad (2)$$

$$c_t = f_t c_{t-1} + i_t \tanh(W_j x_t + U_j h_{t-1} + b_j) \qquad (3)$$

$$o_t = \sigma(W_o x_t + U_o h_{t-1} + b_o) \qquad (4)$$

$$h_t = o_t \tanh(c_t) \qquad (5)$$

A bidirectional LSTM (BLSTM) extends an LSTM network to process input from both sides. This can be useful in AS since the answer may be generated by moving the words in the question. In a BLSTM network, the state vectors $\overrightarrow{h_t}$ and $\overleftarrow{h_t}$ are generated by parsing the input and combining them as $h_t = [\overrightarrow{h_t}, \overleftarrow{h_t}]$. LSTM and BLSTM networks treat all the input samples equally important, leading to network confusion. To cope with this problem, an attention mechanism can be considered. To this end, each state $h_t$ is accompanied by the coefficient $\alpha_t$ so the final state $h$ for a sequence of length $T$ is computed as:

$$h_t = \sum_{t=1}^{T} \alpha_t h_t \qquad (6)$$

## B. Differential Evolution

Differential evolution (DE) [41] has gained widespread recognition as a powerful population-based method capable of effectively solving a wide range of optimization problems [42] DE operates through three essential operations: mutation, crossover, and selection. The DE algorithm commences by initializing a population, usually obtained by sampling from a uniform distribution. This population serves as the foundation for the subsequent evolutionary process. The mutation operator plays a pivotal role in DE, as it generates a mutation vector that introduces diversity and exploration into the population. Through the mutation process, new candidate solutions are created by perturbing the existing individuals in the population. This perturbation is achieved by combining the information from multiple individuals and forming a new candidate solution, often through vector arithmetic operations. The mutation operator in DE typically involves randomly selecting a set of individuals from the population and using their information to compute the mutation vector. This is accomplished by multiplying the difference between two randomly selected individuals by a scaling factor and adding it to a base individual. The resulting mutation vector represents a potential new solution that explores the search space in an attempt to discover better regions of the optimization landscape. The mutation operator in DE plays a crucial role in maintaining population diversity and facilitating exploration. By introducing novel solutions, DE can effectively navigate the optimization landscape and overcome local optima. The quality and diversity of the mutation vector greatly influence the overall performance of DE and its ability to converge to an optimal solution.

The following is the mutation operator that creates a mutation vector:

$$\vec{v}_{i,g} = \vec{x}_{r_1,g} + F\,(\vec{x}_{r_2,g} - \vec{x}_{r_3,g}) \qquad (7)$$

where, $\vec{x}_{r_1,g}$, $\vec{x}_{r_2,g}$ and $\vec{x}_{r_3}$ three distinctive candidate solutions are randomly chosen from the current population, and $F$ is a scale factor.

Mutant and target vectors are combined during the crossover. This can be done using the well-known Binomial crossover:

$$u_{i,j,g} = \begin{cases} v_{i,j,g} & \text{if rand}(0,1) \leq \text{ CR or j } = j_{rand} \\ x_{i,j,g} & \text{otherwise} \end{cases} \qquad (8)$$

where, $CR$ is the crossover ratio, $j_{rand}$ is a random number selected from $\{1,2,\ldots,D\}$ and $D$ is the dimensionality of a candidate solution. After performing crossover, the selection operator selects the target and trial vectors' best solution.

## IV. PROPOSED MODEL

Fig. 1 depicts the general framework of the suggested technique. Pre-processing, word embedding, and prediction are the three key stages of the proposed technique. As a

preliminary stage, unnecessary words and symbols are eliminated. Using DistilBERT, the embedding vector of each word is retrieved in the second stage, and the similarity between the two sentences is predicted. The suggested method employs a clustering-based differential evolution technique to determine the initial seeds of the network weights, while the RL-based algorithm is used to address the class imbalance.

### A. Pre-Processing

Pre-processing is a vital part of any NLP system because the essential characters, words, and sentences identified in this stage are passed to the later stages. Therefore, the pre-processing output has a significant impact on the quality of the final results.

Common stop-word elimination and stemming techniques are employed in the approach. Stop words are part of sentences that can be regarded as overhead. The most common stop words are articles, prepositions, pronouns, etc. They should thus be removed as they cannot function as keywords. For decreasing the dimensionality of the term space, stemming is used to identify the stem of a word. For instance, the terms 'go', 'went', 'going', 'watcher', etc., all can be stemmed from the word "watch". Stemming removes ambiguity and reduces the number of words, time and memory requirements.

### B. Word Embedding

Word embedding is used in deep learning algorithms to compare words with semantic vectors. The best technique to produce accurate context-based representations of highlighted words is to insert words.

Many experiments determine the most effective approach to represent words in neural network models. Recently, predefined language models (PLM), previous natural language information boxes, and tuning have been widely used for NLP activities. PLM models frequently use unlabeled data to learn about the model's parameters.

In this article, DistilBERT is considered as one of the newer methods of the PLM model for word input. DistilBERT is an interactive language model designed on large data sets, such as Wikipedia, in order to produce contextual representations. It is common practice to fine-tune the linear layers of DistilBERT for addressing different classification tasks. Some configuration tools teach classification tasks by extracting semantics from common semantic problems or contexts. Models other than DistilBERT build one-directional embeddings which ignore contextual differences. On the contrary, DistilBERT utilizes a bidirectional transformer by conditioning its representations on the left and right context simultaneously.

### C. Prediction

Our predictive model comprises two attention-based BLSTMs and one feed-forward network. The two BLSTMs extract embeddings for the question and response sentences. The feed-forward network predicts the degree to which two sentences are similar. Consider $Q = (w_1, w_2, \ldots, w_n)$ and $A = (v_1, v_2, \ldots, v_m)$, where $w_i$ and $v_i$ represent the $i$-th word in the question and response, respectively.

Because of the length restriction in BLSTM, $Q$ and $A$ can include only $n$ and $m$ words, respectively (in this work, $n = m$). After feeding $Q$ and $A$ into their respective BLSTMs, the attention mechanism computes their embeddings in the following manner:

$$q = \sum_{i=1}^{n} \alpha_i h_{q_i} \quad (9)$$

$$r = \sum_{i=1}^{m} \beta_i h_{r_i} \quad (10)$$

where, $h_{q_i} = [\overleftarrow{h}_{q_i}, \overrightarrow{h}_{q_i}]$ and $h_{r_i} = [\overleftarrow{h}_{r_i}, \overrightarrow{h}_{r_i}]$ represent the $i$-th hidden vectors in the BLSTM, and $\alpha_i, \beta_i \in [0,1]$ are the $i$-th attention weights for each unit in the BLSTM, calculated as:

$$\alpha_i = \frac{e^{u_i}}{\sum_{j=1}^{n} e^{u_j}} \quad (11)$$

$$\beta_i = \frac{e^{v_i}}{\sum_{j=1}^{m} e^{v_j}} \quad (12)$$
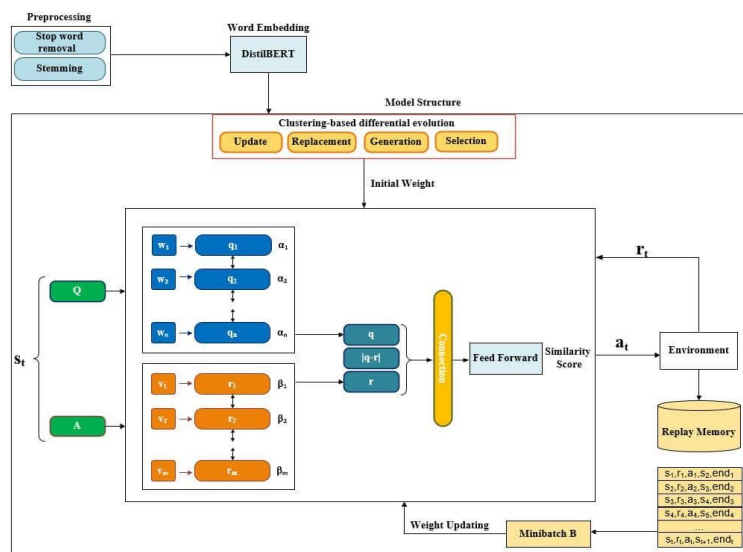


Fig. 1. Overall structure of the proposed model.

$$u_i = tanh(W_u h_{sou_i} + b_u) \qquad (13)$$

$$v_i = tanh(W_v h_{sus_i} + b_v) \qquad (14)$$

where, $W_u$, $W_v$, $b_u$ and $b_v$ are the trainable parameters. As shown in Fig 1, the input of the feed-forward network is the connection of $q$ , $r$ , and $|q - r|$ . The training dataset comprises pairs of positive and negative values. Each positive pair comprises a question and its proper response. Each pair of negatives comprises a question and an improper response. Two training phases comprise the model: pretraining and fine-tuning. During pretraining, the augmented differential evolution algorithm is used to determine the optimal initial weights. The initial weights for the fine-tuning phase are the weights obtained during the pretraining phase.

*1) Pretraining*: The weights of the LSTM, the attention mechanism, and the feed-forward neural network are initialized at this stage. To achieve this, an improved differential evolution method is introduced, incorporating a clustering scheme and a novel fitness function. A clustering-based mutation and update technique is used in the changed DE algorithm to boost the optimization efficiency.

A promising region of the search space is distinguished by the suggested mutation operator, which was inspired by [40]. The k-means clustering algorithm does this by dividing the current set $P$ into $k$ clusters, each representing a distinct region of the search space. The number of clusters was picked at random from $[2, \sqrt{N}]$ . The cluster with the lowest sample means the fit is selected as the optimal group.

The proposed clustering-based mutation is defined as:

$$\overrightarrow{v^{clu}_\iota} = \overrightarrow{win}_g + F \left( \vec{x}_{r_1,g} - \vec{x}_{r_2,g} \right) \qquad (15)$$

where, $\overrightarrow{win}_g$ is the most acceptable solution in the promising region, and $\vec{x}_{r_1,g}$ and $\vec{x}_{r_2,g}$ are two randomly determined candidate solutions from the current population. It should be noted that $\overrightarrow{win}_g$ is not always the population's most acceptable solution. The clustering-based mutation procedure is implemented $M$ times.

The current population is updated when $M$ new solutions have been provoked through clustering-based mutation. The steps are as follows:

- Selection: Generate $k$ individuals randomly as initial seeds of the $k$-means algorithm;

- Generation: Generate $M$ solutions using clustering-based mutation as set $v^{clu}$;

- Replacement: Choose $M$ solutions at random and determine as $B$;

- Update: The best $M$ solutions from the $v^{clu} \cup B$ determined as the $B'$. The new population is afterwards calculated as $(P - B) \cup B'$.

The fundamental structure of the proposed model comprises two LSTM networks with their respective attention mechanisms and a feed-forward network. As depicted in Fig. 2, in the proposed DE algorithm, all weights and bias terms are organized into a vector to generate a candidate solution.

To assess the quality of a candidate solution, the fitness function is defined as:

$$Fitness = \frac{1}{\sum_{i=1}^{N}(y_i - \tilde{y}_i)^2} \qquad (16)$$

where, $T$ is the total number of training samples, $y_i$ is the $i$-th desired target, and $\tilde{y}_i$ is model prediction.

*2) Classification*: An RL-based algorithm is employed to tackle the imbalance problem caused by varying data volumes in the classes. Each question-and-answer pair in the training dataset makes up a state of the environment, and the network is the agent that performs a sequence of classifications on all pairs. When the agent predicts the class label of a pair, it is taking an action: the pair seen at the $t^{th}$ time-step is the state $s_t$ , and the classification performed is $a_t$ . In return, the environment provides a reward, $r_t$, to guide the agent. Reward values are assigned such that classifying a sample from the majority class garners a lower absolute value compared to the minority class. The reward function is:
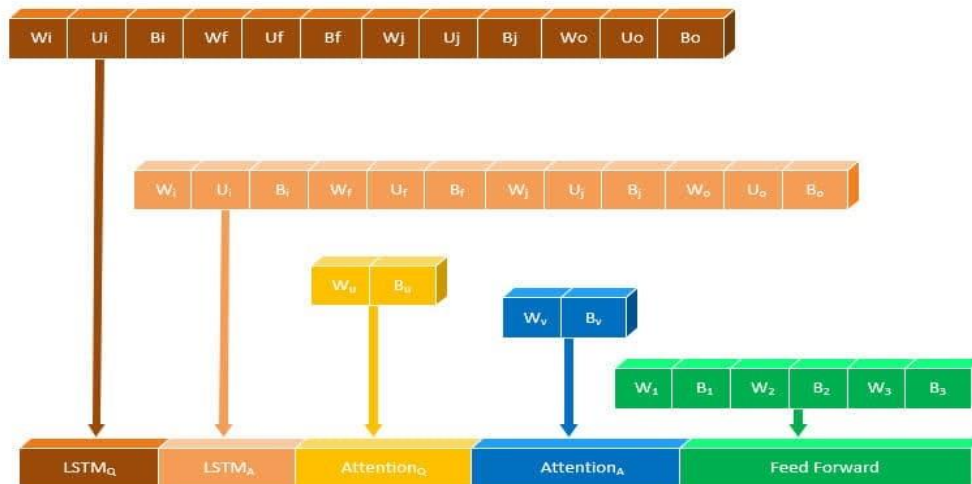


Fig. 2.     Encoding strategy in the proposed algorithm.

$$(s_t, a_t, l_t) = \begin{cases} +1 \,, a_t = l_t \text{ and } s_t \in D_P \\ -1 \,, a_t \neq l_t \text{ and } s_t \in D_P \\ \lambda \,, a_t = l_t \text{ and } s_t \in D_N \\ -\lambda \,, a_t \neq l_t \text{ and } s_t \in D_N \end{cases} \quad (17)$$

where, $D_P$ and $D_N$ are the means of the minority and majority classes, respectively. Correct/incorrect classification of a sample from the majority class yields a reward of $+\lambda / -\lambda$, where $0 < \lambda < 1$.

The agent's objective in deep Q-learning is action selection such that the sum of discounted future rewards ($R_t$) are maximized:

$$R_t = \sum_{t'=t}^{T} \gamma^{t'-t} r_{t'} \quad (18)$$

where, $\gamma$ is the discount factor, $r_{t'}$ is the immediate reward at time step $t'$, and $T$ is the last time-step of the episode. Using $\gamma$, more importance is given to rewards in the near future (closer to the current time step $t$) compared to the distant future. Each episode is terminated if all of the samples are classified correctly or at least one sample from the minority class is misclassified. The expected return of taking action $a$ in state $s$ at time step $t$ and following policy $\pi$ afterwards is computed as:

$$Q^\pi(s, a) = E[R_t | s_t = s, a_t = a, \pi] \quad (19)$$

where, $Q^\pi(s, a)$ is called the action-value function. At each state $s$, the optimal action is the one that maximizes the action-value function:

$$Q^*(s, a) = max_\pi E[R_t | s_t = s, a_t = a, \pi] \quad (20)$$

where, maximization is taken over all possible policies, the recursive form of equation 20 can be written as:

$$Q^*(s, a) = E[r + \gamma \, max_{a'} Q^*(s', a') | s_t = s, a_t = a] \quad (21)$$

The best action-value function can be estimated iteratively using the Bellman equation:

$$Q_{i+1}(s, a) = E[r + \gamma \, max_{a'} Q_i(s', a') | s_t = s, a_t = a] \quad (22)$$

During training, upon observing state $s$, the policy network outputs action $a$. After executing this action, the environment returns a reward $r$, and the next state becomes $s'$. The tuple $(s, a, r, s')$ is then saved into the replay memory $M$. Minibatches $B$ of these tuples are drawn randomly from the replay memory, which is used to update the network parameters via gradient descent. The update is done based on the following loss function:

$$L_i(\theta_i) = \sum_{(s,a,r,s') \in B} (y - Q(s, a; \theta_i))^2 \quad (23)$$

where, $\theta_i$ is the network parameters at $i$-th training iteration, and $y$ is the estimated target for the $Q$ function. The desired target $y$ is equal to the immediate reward for the state-action pair plus the discounted maximum future Q value:

$$y = r + \gamma \, max_{a'} Q(s', a'; \theta_{k-1}) \quad (24)$$

For terminal states, $y$ is equal to $r$. At $ith$ iteration, the gradient of the loss function is calculated as follows:

$$\nabla_{\theta_i} L(\theta_i) = -2 \sum_{(s,a,r,s') \in B} (y - Q(s, a; \theta_i)) \nabla_{\theta_i} Q(s, a; \theta_i) \quad (25)$$

The network weights are updated using the gradient of loss function computed as follows:

$$\theta_{i+1} = \theta_i + \alpha \nabla_{\theta_i} Q(s, a; \theta_i) \quad (26)$$

where, $\alpha$ is the learning rate.

## V. EXPERIMENTAL RESULTS

In this section, the conducted experiments are detailed.

### A. Datasets

The following three benchmark databases are used during the experiments (see Table I for their statistics):

- TrecQA [43] is taken from the TREC trace dataset. Yao et al. [44] used two training datasets, TRAIN, and TRAIN-ALL, to construct an extended set of positive and negative pairs. The soundness of answers in the TRAIN-ALL dataset is verified automatically by matching pairs with regular expressions. The TRAIN, DEV, and TEST data set' responses were all manually assessed. To teach the model, the TRAIN-ALL set is utilized.

- LegalQA [45] is a database of legal question-and-answer submissions from the Chinese community. Inquiries were answered online by a licensed attorney. The four fields that make up LegalQA are Question Title, Question Text, Answer, and Label. A straight line designates real positive couples.

- A Wikipedia page that is regarded as a subject of the year is linked to each question in the open-source quality assurance dataset known as WikiQA. [46]. To avoid ambiguity in the answer sentences, all the answers at the bottom of the page are the candidates' answers.

### B. Metrics

According to earlier research, the most popular reference points for the answer-selection task are MAP and MRR [47]. MAP evaluates the capacity to categorize responses and return solutions. If a high score match is found, the MRR is repeated. The average accuracy is derived using the Mean Average Precision (MAP) findings:

TABLE I. STATISTICAL INFORMATION FROM THE LEGALQA, TRECQA AND WIKIQA DATASETS

| dataset | Question | | | QA pairs | | | Correct | | |
|---------|----------|-----|------|----------|-----|------|---------|------|------|
| | train | dev | test | train | dev | test | train | dev | test |
| LegalQA | 10,526 | 1,593 | 3,035 | 100,590 | 11,965 | 26,913 | 21.8 | 24.4 | 22.9 |
| TracQA | 1,229 | 82 | 100 | 53,417 | 1,148 | 1,517 | 12.0 | 19.3 | 18.7 |
| WikiQA | 873 | 126 | 243 | 20,360 | 1,130 | 2,352 | 12.0 | 12.4 | 12.5 |

$$MAP(Q) = \frac{1}{|Q|}\sum_{i=1}^{|Q|}\frac{1}{n_i}\sum_{j=1}^{n_i} Precision\ (R_{ij}) \quad (27)$$

where, $Q$ is the questions set, $n_i$ is the number of relevant answers to $i$-th question, and $R_{ij}$ is the set of j best candidates selected from the $n_i$ available answers. The position of the first correct response is used to determine the Mean Reciprocal Rank (MRR) calculated as follows:

$$MRR\ (Q) = \frac{1}{|Q|}\sum_{i=1}^{|Q|}\frac{1}{r_i} \quad (28)$$

where, $r_i$ denotes the first response's placement for $i$-th question. Details of model

The experiments were implemented using Python and PyTorch. For natural language processing in Python, the NLTK package was leveraged. A two-layer LSTM with a hidden size of 64 was employed. Also, because there are connections between the vectors in the two LSTM networks, the batch must be normalized before it is sent to the feed-forward neural network. The tests were conducted using a computer with 64 GB Memory, a 64-bit Windows operating system, and a graphics processing unit (GPU). The most effective models for LegalQA, TrecQA, and WikiQA were identified after 50, 60, and 100 epochs. For the three datasets, training took 5, 20, and 60 hours, respectively.

*C. Model Performance*

First, the system was tested against nine deep learning-based strategies, including KABLSTM [48], EATS [49], AM-BLSTM [50], BERT-Base [51], DRCN [52], P-CNN [53], DARCNN [54], DASL [55], IKAAS [56]. The outcomes for the three datasets—LegalQA, TrecQA, and WikiQA—are presented in Table II. All the trials were carried out five times to avoid the randomness of heuristic algorithms influencing the

findings. Results using random weight initialization (Proposed (no RL and DE)), enhanced DE (Proposed (no RL)), RL use (Proposed (no DE)), and the entire model are shown for the suggested method (Proposed).

Table III displays the extent to which the proposed method outperforms other methods. The proposed model consistently demonstrates a significant advantage over other widely-recognized methods in the domain. When examining the MRR and MAP metrics specifically for the LegalQA dataset, the proposed model exhibits enhancements ranging from +0.077 to +0.231, with the most pronounced improvement observed against the DARCNN method. This consistent performance is evident across all datasets, underscoring the robustness and adaptability of the proposed approach. Notably, even the variants of the proposed model, such as "Proposed (no RL and DE)" and "Proposed (no RL)", consistently outpace most other techniques. These modified versions, despite lacking certain features, still deliver commendable results, emphasizing the intrinsic strength of the primary model. An intriguing point is the comparison between the BERT-Base and its more streamlined version, DistilBERT. While BERT-Base stands as a powerful model in the NLP realm, the margin table shows that the approach of the proposed model surpasses it, attesting to the innovative methods integrated into the new model. Addressing Imbalance: The performances of models like P-CNN and DARCNN, especially the substantial gains in specific metrics such as +0.285 for TrecQA (MRR) and +0.231 for LegalQA (MRR), shed light on the challenges presented by data imbalance in the AS domain. The resilience and adaptability of the proposed model to such challenges, coupled with its ability to deliver top-notch results, underscore its potential in addressing imbalanced datasets effectively.

TABLE II. PERFORMANCE COMPARISON OF THE PROPOSED MODEL WITH THOSE ALREADY IN USE ON THREE DATASETS: RESULTS USING THE DAG MARKER WERE FOUND IN EARLIER STUDIES

| Method | LegalQA | | TrecQA | | WikiQA | |
|---|---|---|---|---|---|---|
| | *MRR* | *MAP* | *MRR* | *MAP* | *MRR* | *MAP* |
| KABLSTM | 0.752 | 0.784 | 0.792† | 0.844† | 0.732† | 0.749† |
| EATS | 0.780 | 0.838 | 0.854† | 0.881† | 0.700† | 0.715† |
| AM-BLSTM | 0.787 | 0.814 | 0.806 | 0.842 | 0.843 | 0.794 |
| BERT-Base | 0.830 | 0.841 | 0.837 | 0.831 | 0.816† | 0.828† |
| DRCN | 0.856 | 0.846 | 0.823 | 0.846 | 0.804† | 0.862† |
| P-CNN | 0.735 | 0.742 | 0.673 | 0.714 | 0.734† | 0.737† |
| DARCNN | 0.708 | 0.752 | 0.765 | 0.748 | 0.734† | 0.750† |
| DASL | 0.821 | 0.815 | 0.846 | 0.848 | 0.781 | 0.778 |
| IKAAS | 0.825† | 0.883† | 0.823† | 0.868† | 0.846 | 0.845 |
| Proposed (no RL and DE) | 0.742 ± 0.017 | 0.826 ± 0.005 | 0.791 ± 0.014 | 0.825 ± 0.025 | 0.759 ± 0.017 | 0.732 ± 0.015 |
| Proposed (no RL) | 0.796 ± 0.021 | 0.841 ± 0.019 | 0.831 ± 0.026 | 0.856 ± 0.026 | 0.831 ± 0.014 | 0.843 ± 0.048 |
| Proposed (no DE) | 0.862 ± 0.019 | 0.859 ± 0.031 | 0.858 ± 0.019 | 0.874 ± 0.016 | 0.849 ± 0.012 | 0.856 ± 0.010 |
| Proposed | 0.939 ± 0.018 | 0.955 ± 0.096 | 0.958 ± 0.039 | 0.941 ± 0.085 | 0.912 ± 0.035 | 0.929 ± 0.031 |

TABLE III.    MARGIN OF IMPROVEMENT OF THE PROPOSED MODEL OVER OTHER METHODS

| Method | LegalQA | | TrecQA | | WikiQA | |
|---|---|---|---|---|---|---|
| | *MRR* | *MAP* | *MRR* | *MAP* | *MRR* | *MAP* |
| KABLSTM | +0.187 | +0.171 | +0.166 | +0.097 | +0.180 | +0.180 |
| EATS | +0.159 | +0.117 | +0.104 | +0.060 | +0.212 | +0.214 |
| AM-BLSTM | +0.152 | +0.141 | +0.152 | +0.099 | +0.069 | +0.135 |
| BERT-Base | +0.109 | +0.114 | +0.121 | +0.110 | +0.096 | +0.101 |
| DRCN | +0.083 | +0.109 | +0.135 | +0.095 | +0.108 | +0.067 |
| P-CNN | +0.204 | +0.213 | +0.285 | +0.227 | +0.178 | +0.192 |
| DARCNN | +0.231 | +0.203 | +0.193 | +0.193 | +0.178 | +0.179 |
| DASL | +0.118 | +0.140 | +0.112 | +0.093 | +0.131 | +0.151 |
| IKAAS | +0.114 | +0.072 | +0.135 | +0.073 | +0.066 | +0.084 |
| Proposed (no RL and DE) | +0.197 | +0.129 | +0.167 | +0.116 | +0.153 | +0.197 |
| Proposed (no RL) | +0.143 | +0.114 | +0.127 | +0.085 | +0.081 | +0.086 |
| Proposed (no DE) | +0.077 | +0.096 | +0.100 | +0.067 | +0.063 | +0.073 |

*1) Comparison with other metaheuristics*: In this section, a variety of meta-heuristic optimization algorithms are compared to the enhanced DE algorithm. To do this, a variety of meta-heuristics are employed while maintaining the integrity of the other model elements, such as pre-processing, word embedding, LSTM, network structure, and RL, in order to gain the initial model parameters. Eight different algorithms, including (standard) DE [57], grey wolf optimization (GWO) [58], bat algorithm (BA) [59], dragonfly algorithm (DA) [47], salp swarm algorithm (SSA) [60], cuckoo optimization algorithm (COA) [61], human mental search (HMS) [40], whale optimization algorithm (WOA) [62], and artificial bee colony (ABC) [63] are investigated.

The overall size of all algorithms and their predicted capacities were calculated to be 150 and 4,000, respectively. In Table IV, the default settings can be observed. Table V displays the findings for each of the three data sets. On every dataset, the suggested DE algorithm performs better than any other algorithm, as shown. Normal DE is the runner-up.

TABLE IV.    SETTING PARAMETERS FOR META-HEURISTICS

| algorithm | parameter | value |
|---|---|---|
| DE | scaling factor | 0.4 |
| | crossover probability | 0.7 |
| BAT | loudness update constant | 0.60 |
| | emission rate update constant | 0.50 |
| | initial pulse emission rate | 0.001 |
| COA | alien solutions discovery rate | 0.25 |
| HMS | Maximum mental processes | 5 |
| | C | 1 |
| | loudness update constant | 0.50 |
| WOA | b | 1 |
| ABC | limit | ne× dimensionality |
| | no | 50% of the colony |
| | ne | 50% of the colony |
| | ns | 1 |

TABLE V.    RESULTS OF META-HEURISTIC ALGORITHMS ON THE DATASETS FROM LEGALQA, TRECQA, AND WIKIQA

| Method | LegalQA | | TrecQA | | WikiQA | |
|---|---|---|---|---|---|---|
| | *MRR* | *MAP* | *MRR* | *MAP* | *MRR* | *MAP* |
| DE | $0.915 \pm 0.019$ | $0.933 \pm 0.015$ | $0.890 \pm 0.046$ | $0.916 \pm 0.191$ | $0.872 \pm 0.036$ | $0.911 \pm 0.009$ |
| GWO | $0.774 \pm 0.116$ | $0.771 \pm 0.090$ | $0.741 \pm 0.075$ | $0.783 \pm 0.134$ | $0.742 \pm 0.038$ | $0.771 \pm 0.016$ |
| BAT | $0.855 \pm 0.013$ | $0.809 \pm 0.028$ | $0.867 \pm 0.088$ | $0.874 \pm 0.295$ | $0.842 \pm 0.071$ | $0.863 \pm 0.090$ |
| DA | $0.809 \pm 0.085$ | $0.819 \pm 0.039$ | $0.859 \pm 0.015$ | $0.876 \pm 0.053$ | $0.816 \pm 0.090$ | $0.850 \pm 0.083$ |
| SSA | $0.739 \pm 0.030$ | $0.756 \pm 0.081$ | $0.745 \pm 0.082$ | $0.756 \pm 0.017$ | $0.739 \pm 0.053$ | $0.753 \pm 0.023$ |
| COA | $0.857 \pm 0.091$ | $0.883 \pm 0.015$ | $0.880 \pm 0.073$ | $0.895 \pm 0.249$ | $0.870 \pm 0.013$ | $0.860 \pm 0.019$ |
| HMS | $0.841 \pm 0.010$ | $0.875 \pm 0.193$ | $0.875 \pm 0.018$ | $0.890 \pm 0.047$ | $0.837 \pm 0.159$ | $0.863 \pm 0.159$ |
| WOA | $0.752 \pm 0.016$ | $0.753 \pm 0.027$ | $0.769 \pm 0.05$ | $0.789 \pm 0.085$ | $0.731 \pm 0.000$ | $0.760 \pm 0.018$ |
| ABC | $0.873 \pm 0.014$ | $0.896 \pm 0.038$ | $0.875 \pm 0.025$ | $0.889 \pm 0.015$ | $0.872 \pm 0.020$ | $0.881 \pm 0.010$ |

*2) Reward function*: The reward function directs the agent toward achieving its aim by giving the right ratings to certain activities. ±1 and ±$\lambda$ were selected as the rewards for the minority and majority classes, respectively. The ratio of the sample size of the majority class to the minority class determines the $\lambda$ value. As the majority/minority ratio rises, the $\lambda$ value decreases. The majority class bonus is held constant, and $\lambda$ is chosen from the set {0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8,0.9,1} to see how changing $\lambda$ affects the reward earned by the model. The evaluation findings for the three datasets are displayed in Fig. 3. The reward plots in Fig. 3(a), Fig. 3(b), and Fig. 3(c) all have an ascending trend for $\lambda < 0.4$ and a decreasing trend for $\lambda > 0.4$. The relevance of majority classes is disregarded for $\lambda = 0$, while for $\lambda = 1$, both classes are regarded as equally significant. Even though the minority is more important to us, the impact of the majority should not be ignored.

*3) Examples*: A qualitative example is provided to evaluate the efficacy of RL in the model, focusing on the question "Who is the president or chief executive of Amtrak?" from the TrecQA dataset. The results of the top five answers

retrieved by the model with and without using RL are shown in Fig. 4. As seen, models without RL are more likely to select negative answers. The model with RL gives the highest possible score for answering the question.Word embeddings.

In this section, performing the DistilBERT adopted in the method for word embedding is compared against five other word embedding methods. One-Hot Encoding [64] creates binary properties for each class and assigns values to the properties in each instance that corresponds to a specific class. CBOW and Skip-gram [65] use neural networks to compare words with insertion vectors. GloVe [66] is an unattended learning algorithm implemented for full word set statistics. FastText [67] [65] extends the Skip-gram model, in which each word is represented by an n-gram character instead of learning a vector for words. Table VI shows the results of the conducted experiment. As expected, One-Hot cryptography has the lowest performance among the evaluated methods. CBOW and Skip-gram perform similarly, and both yield better performance compared to GloVe, while FastText gives better results. However, the best performance is claimed by the DistilBERT model, which is the motivation behind its use in the approach.
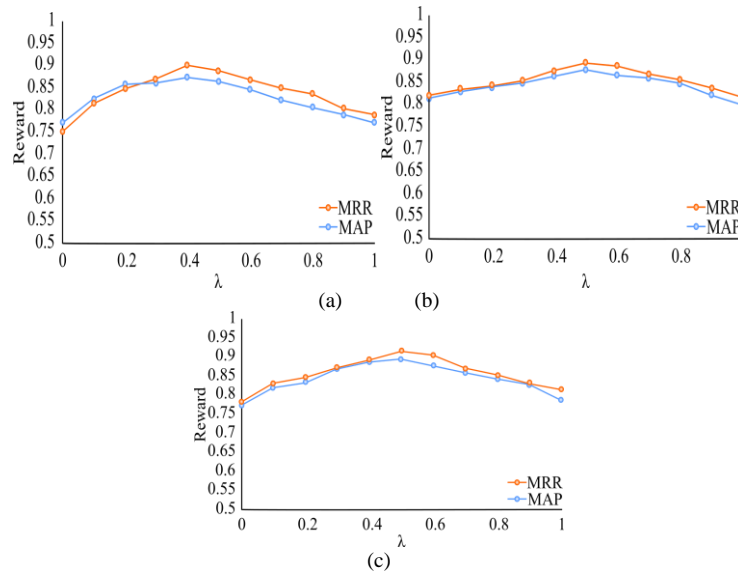


Fig. 3. Reward vs. $\lambda$ for (a) LegalQA dataset, (b) TrecQA dataset, and (c) WikiQA dataset.

| Rank | Ranked answers w/o RL | Ranked answers by RL |
|------|----------------------|----------------------|
| 1 | **george warrington**, amtrak's president, said ridership was up because service was better and because" the marketplace is feeling increasingly frustrated with the alternatives, " namely jammed highways and delayed airplanes. | "long-term success here has to do with doing it right, getting it right and increasing market share, "said **george warrington**, amtrak's president and chief executive. |
| 2 | amtrak president **george warrington** said settling out-of-court was the right thing to do. | amtrak president **george warrington** said settling out-of-court was the right thing to do. |
| 3 | amtrak is offering a deal it hopes few travelers can resist: get good service or a free ride. | amtrak president **george warrington** told the committee that the railway expects delivery next week of the first of 20 high-speed trains for the boston -to- washington northeast corridor. |
| 4 | amtrak spokesman john wolf estimated that only one out of every 1,000 passengers will request a refund voucher. | "amtrak is committed to treating all employees fairly, "amtrak president **george warrington** said in a statement. |
| 5 | amtrak president **george warrington** told the committee that the railway expects delivery next week of the first of 20 high-speed trains for the boston-to-washington northeast corridor. | **george warrington**, amtrak's president, said ridership was up because service was better and because" the marketplace is feeling increasingly frustrated with the alternatives," namely jammed highways and delayed airplanes. |

Fig. 4. " Who is the president or CEO?" This table shows the top 5 answers for models with and without RL. " George Warrington" is the field answer, and the underlined word refers to that term.

TABLE VI.    RESULTS OF DIFFERENT WORD EMBEDDINGS ON THE THREE DATASETS

| Word embedding | LegalQA | | TrecQA | | WikiQA | |
|---|---|---|---|---|---|---|
| | *MRR* | *MAP* | *MRR* | *MAP* | *MRR* | *MAP* |
| One Hot encoding | 0.679 ± 0.042 | 0.569 ± 0.002 | 0.711 ± 0.120 | 0.653 ± 0.081 | 0.649 ± 0.089 | 0.589 ± 0.093 |
| CBOW | 0.851 ± 0.027 | 0.840 ± 0.015 | 0.880 ± 0.081 | 0.861 ± 0.126 | 0.838 ± 0.023 | 0.820 ± 0.019 |
| Skip-gram | 0.874 ± 0.052 | 0.872 ± 0.075 | 0.878 ± 0.030 | 0.858 ± 0.002 | 0.847 ± 0.014 | 0.853 ± 0.014 |
| Glove | 0.812 ± 0.027 | 0.853 ± 0.082 | 0.795 ± 0.140 | 0.821 ± 0.074 | 0.782 ± 0.039 | 0.806 ± 0.009 |
| FastText | 0.879 ± 0.012 | 0.901 ± 0.041 | 0.886 ± 0.093 | 0.876 ± 0.002 | 0.861 ± 0.099 | 0.870 ± 0.000 |

*4) Discussion*: The proposed model in this study addressed the class imbalance issue in AS by employing a reinforcement learning-based technique. Unlike traditional methods that treat it as a binary classification problem, the proposed approach formulated it as a sequence of sequential decisions. An agent classified each instance and received a reward at each step. To handle class imbalance, the reward assigned to the majority class was intentionally lower than that for the minority class. The parameters of the policy were initialized using an improved DE technique. To improve the efficiency of the DE algorithm, a novel cluster-based mutation operator was introduced. This operator utilized the K-means clustering approach to identify the winning cluster and incorporated potentially viable solutions into the existing population. In terms of word embedding, the model employed the DistilBERT model, which reduced the size of the BERT model. To evaluate the effectiveness of the proposed model, extensive experiments were conducted using LegalQA, TrecQA, and WikiQA datasets. The results demonstrated the superiority of the proposed model compared to existing methods in the field of answer selection. However, it is important to acknowledge certain limitations of the proposed model, which can be considered in future work:

*a) Limited Scope*: While the article introduces a novel reinforcement learning-based technique to address class imbalance in AS, it is important to acknowledge that class imbalance is a widely recognized challenge in machine learning, and various approaches have been proposed in the literature. A more comprehensive discussion that explores alternative methods, such as data resampling techniques (e.g., oversampling, under sampling), cost-sensitive learning, or ensemble-based methods, would provide a broader perspective on addressing the class imbalance in AS tasks. Comparing the proposed technique with these alternative approaches in terms of effectiveness and applicability would enhance the understanding of its limitations and potential alternatives.

*b) Lack of Real-World Application*: The evaluation of the proposed model on LegalQA, TrecQA, and WikiQA datasets provides insights into its performance within specific domains. However, it is important to recognize that these datasets might not fully capture the complexities and variations present in real-world AS scenarios. To overcome this limitation, future research should consider evaluating the proposed technique on diverse datasets from different domains, such as medical, finance, or customer support, to assess its generalizability and robustness across various real-world applications. This would provide a more comprehensive

understanding of the technique's effectiveness and limitations in practical settings.

*c) Performance Metrics and Statistical Significance*: While the article claims superiority over existing methods, it is essential to provide a detailed analysis of the performance metrics used for evaluation. Precision, recall, F1-score, and other relevant metrics should be reported, along with the corresponding confidence intervals or statistical tests, to establish the statistical significance of the results. A thorough analysis of these metrics would provide a clearer understanding of the proposed technique's performance and its potential limitations in different AS scenarios.

*d) Computational Efficiency*: While the utilization of the DistilBERT model is mentioned to enhance computational efficiency, it would be beneficial to provide more specific details about the computational resources required by the proposed technique. Comparing the computational requirements, such as memory usage and processing time, with other state-of-the-art AS methods would allow for a more comprehensive assessment. Additionally, considering the scalability of the technique for larger datasets or real-time applications would provide insights into its feasibility and practical utility in various contexts.

*e) Interpretability and Explainability*: The article lacks discussion on the interpretability and explainability of the proposed technique. In AS tasks, understanding the decision-making process and providing explanations for selected answers are important factors for trust and transparency. Discussing methods or approaches used to interpret and explain the decisions made by the reinforcement learning-based model would enhance its applicability in real-world scenarios. Consideration of techniques like attention mechanisms or post-hoc interpretability methods (e.g., LIME, SHAP) would provide insights into the reasoning behind answer selections and potential biases or limitations associated with the model's decisions.

*f) User Feedback and Adaptability*: The article does not discuss the potential for incorporating user feedback or adapting the AS system over time. AS models that can learn from user interactions, such as reinforcement learning with online learning or active learning approaches, have the potential to improve their performance based on user preferences and changing information needs. Investigating the integration of user feedback and methods for continuous adaptation would be valuable for enhancing the proposed technique's effectiveness and user satisfaction.

*g) Comparison with Human Performance*: The article focuses on comparing the proposed model with existing methods, but it does not include a comparison with human

performance. AS tasks often involve subjective judgments, and comparing the performance of the proposed technique with human experts or crowd-sourced annotations can provide valuable insights into the model's strengths and limitations. Conducting experiments that involve human evaluations would help contextualize the performance of the proposed technique and highlight areas where further improvements are needed.

*h) Ensuring Data Quality and Model Performance*: Another aspect warranting discussion is the challenge of recognizing datasets that may potentially misguide the classifier. Any model's efficiency is contingent upon the quality and reliability of its training data. Datasets that contain noisy, inconsistent, or unrepresentative samples can induce biases in the model, leading to flawed predictions. Regular monitoring of performance metrics on validation sets can provide early indications of a model being misguided by its data. A substantial divergence between training and validation performance may hint towards potential dataset issues. Tools like ChatGPT and other advanced language models can offer benefits in this scenario. These models, with their vast training on diverse textual data, can be harnessed to validate the coherence and authenticity of data samples. For instance, they could generate synthetic samples for augmentation, thereby balancing datasets and mitigating risks. They can also be employed to highlight potential anomalies or inconsistencies within a dataset, aiding in its refinement and preprocessing. In future studies, integrating insights from these tools could be an invaluable step for data validation, ensuring models are trained on high-quality, representative datasets.

## VI. CONCLUSION

In this paper, an approach for efficient AS is proposed, which employs enhanced DE algorithms for pretraining and RL for instructing the BP algorithm. The method is based on LSTM with an attention mechanism and DistilBERT word embedding. The proposed model categorizes both positive and negative classes and comprises pairs of positive inquiries and detailed responses. Because the dataset contains many negative pairs, the proposed model produces an unbalanced classification. To address this issue, the approach is framed as a logical decision-making process. Correct classification of minority samples is rewarded with higher values at each episode step than the correct classification of the majority samples. Each episode is repeated until a minority sample is misclassified or all samples are correctly classified. The policy weights were initialized using an improved DE algorithm. The improved DE algorithm clusters the current population and finds promising regions in the search space using a new upgrade strategy. The evaluation of the proposed method was conducted using the LegalQA, TrecQA, and WikiQA datasets, demonstrating its superior performance compared to other methods.

In addition to the proposed classification approach, there are several promising avenues for future research in the field of Natural Language Processing (NLP). One area of interest is exploring the utility of the proposed approach in various NLP applications beyond answer selection. By applying the same reinforcement learning-based technique to tasks such as sentiment analysis, text summarization, or named entity recognition, Insights into the effectiveness and generalizability across different domains can be gained through the study.

Another promising direction for future research is the provision of candidate answers to given questions. While the proposed approach focuses on selecting the best answer from a given list of options, the generation of candidate answers could further enhance the AS process. One potential approach to generating candidate answers is through the use of Generative Adversarial Networks (GANs). GANs have shown promise in generating realistic and coherent text, and their application in generating diverse and plausible candidate answers could greatly enrich the AS process. Further investigation into the integration of GANs with the proposed classification approach could lead to more comprehensive and accurate answer selection systems.

## REFERENCES

[1] L. Hong et al., "GAN-LSTM-3D: An efficient method for lung tumour 3D reconstruction enhanced by attention-based LSTM," CAAI Trans Intell Technol, 2023.

[2] J. Huang, "A multi-size neural network with attention mechanism for answer selection," arXiv preprint arXiv:2105.03278, 2021.

[3] S. Zhang, X. Zhang, H. Wang, J. Cheng, P. Li, and Z. Ding, "Chinese medical question answer matching using end-to-end character-level multi-scale CNNs," Applied Sciences, vol. 7, no. 8, p. 767, 2017.

[4] X. Xu, F. Shen, Y. Yang, H. T. Shen, and X. Li, "Learning discriminative binary codes for large-scale cross-modal retrieval," IEEE Transactions on Image Processing, vol. 26, no. 5, pp. 2494–2507, 2017.

[5] S.-J. Yen, Y.-C. Wu, J.-C. Yang, Y.-S. Lee, C.-J. Lee, and J.-J. Liu, "A support vector machine-based context-ranking model for question answering," Inf Sci (N Y), vol. 224, pp. 77–87, 2013.

[6] W. Yin, M. Yu, B. Xiang, B. Zhou, and H. Schütze, "Simple question answering by attentive convolutional neural network," arXiv preprint arXiv:1606.03391, 2016.

[7] S. V. Moravvej, A. Mirzaei, and M. Safayani, "Biomedical text summarization using conditional generative adversarial network (CGAN)," arXiv preprint arXiv:2110.11870, 2021.

[8] S. V Moravvej, M. J. Maleki Kahaki, M. Salimi Sartakhti, and M. Joodaki, "Efficient GAN-based method for extractive summarization," Journal of Electrical and Computer Engineering Innovations (JECEI), vol. 10, no. 2, pp. 287–298, 2022.

[9] R. S. Sexton, R. E. Dorsey, and J. D. Johnson, "Optimization of neural networks: A comparative analysis of the genetic algorithm and simulated annealing," Eur J Oper Res, vol. 114, no. 3, pp. 589–601, 1999.

[10] S. Mirjalili and S. Mirjalili, "Genetic algorithm," Evolutionary Algorithms and Neural Networks: Theory and Applications, pp. 43–55, 2019.

[11] C. A. R. de Sousa, "An overview on weight initialization methods for feedforward neural networks," in 2016 International Joint Conference on Neural Networks (IJCNN), IEEE, 2016, pp. 52–59.

[12] A. Ranganathan, "The levenberg-marquardt algorithm," Tutorial on LM algorithm, vol. 11, no. 1, pp. 101–110, 2004.

[13] S. Vakilian, S. V. Moravvej, and A. Fanian, "Using the artificial bee colony (ABC) algorithm in collaboration with the fog nodes in the Internet of Things three-layer architecture," in 2021 29th Iranian Conference on Electrical Engineering (ICEE), IEEE, 2021, pp. 509–513.

[14] S. Vakilian, S. V. Moravvej, and A. Fanian, "Using the cuckoo algorithm to optimizing the response time and energy consumption cost of fog nodes by considering collaboration in the fog layer," in 2021 5th International Conference on Internet of Things and Applications (IoT), IEEE, 2021, pp. 1–5.

[15] R. Storn and K. Price, "Differential evolution–a simple and efficient heuristic for global optimization over continuous spaces," Journal of global optimization, vol. 11, pp. 341–359, 1997.

[16] S. V. Moravvej, S. J. Mousavirad, M. H. Moghadam, and M. Saadatmand, "An LSTM-based plagiarism detection via attention mechanism and a population-based approach for pre-training parameters with imbalanced classes," in Neural Information Processing: 28th International Conference, ICONIP 2021, Sanur, Bali, Indonesia, December 8–12, 2021, Proceedings, Part III 28, Springer, 2021, pp. 690–701.

[17] S. Danaei et al., "Myocarditis Diagnosis: A Method using Mutual Learning-Based ABC and Reinforcement Learning," in 2022 IEEE 22nd International Symposium on Computational Intelligence and Informatics and 8th IEEE International Conference on Recent Achievements in Mechatronics, Automation, Computer Science and Robotics (CINTI-MACRo), IEEE, 2022, pp. 265–270.

[18] M. Schütz, A. Schindler, M. Siegel, and K. Nazemi, "Automatic fake news detection with pre-trained transformer models," in Pattern Recognition. ICPR International Workshops and Challenges: Virtual Event, January 10-15, 2021, Proceedings, Part VII, Springer, 2021, pp. 627–641.

[19] H. Han, W.-Y. Wang, and B.-H. Mao, "Borderline-SMOTE: a new over-sampling method in imbalanced data sets learning," in International conference on intelligent computing, Springer, 2005, pp. 878–887.

[20] A. R. B. Alamsyah, S. R. Anisa, N. S. Belinda, and A. Setiawan, "Smote and nearmiss methods for disease classification with unbalanced data: Case study: IFLS 5," in Proceedings of The International Conference on Data Science and Official Statistics, 2021, pp. 305–314.

[21] S. Gu, E. Holly, T. Lillicrap, and S. Levine, "Deep reinforcement learning for robotic manipulation with asynchronous off-policy updates," in 2017 IEEE international conference on robotics and automation (ICRA), IEEE, 2017, pp. 3389–3396.

[22] S. V. Moravvej et al., "RLMD-PA: A reinforcement learning-based myocarditis diagnosis combined with a population-based algorithm for pretraining weights," Contrast Media Mol Imaging, vol. 2022, 2022.

[23] A. Severyn and A. Moschitti, "Automatic feature engineering for answer selection and extraction," in Proceedings of the 2013 Conference on Empirical Methods in Natural Language Processing, 2013, pp. 458–467.

[24] S. W. Yih, M.-W. Chang, C. Meek, and A. Pastusiak, "Question answering using enhanced lexical semantic models," in Proceedings of the 51st Annual Meeting of the Association for Computational linguistics, 2013.

[25] S. Wang and J. Jiang, "A compare-aggregate model for matching text sequences," arXiv preprint arXiv:1611.01747, 2016.

[26] S. Yoon, F. Dernoncourt, D. S. Kim, T. Bui, and K. Jung, "A compare-aggregate model with latent clustering for answer selection," in Proceedings of the 28th ACM international conference on information and knowledge management, 2019, pp. 2093–2096.

[27] A. Severyn and A. Moschitti, "Learning to rank short text pairs with convolutional deep neural networks," in Proceedings of the 38th international ACM SIGIR conference on research and development in information retrieval, 2015, pp. 373–382.

[28] D. Wang and E. Nyberg, "A long short-term memory model for answer sentence selection in question answering," in Proceedings of the 53rd Annual Meeting of the Association for Computational Linguistics and the 7th International Joint Conference on Natural Language Processing (Volume 2: Short Papers), 2015, pp. 707–712.

[29] L. Yu, K. M. Hermann, P. Blunsom, and S. Pulman, "Deep learning for answer sentence selection," arXiv preprint arXiv:1412.1632, 2014.

[30] M. Feng, B. Xiang, M. R. Glass, L. Wang, and B. Zhou, "Applying deep learning to answer selection: A study and an open task," in 2015 IEEE workshop on automatic speech recognition and understanding (ASRU), IEEE, 2015, pp. 813–820.

[31] H. T. Madabushi, M. Lee, and J. Barnden, "Integrating question classification and deep learning for improved answer selection," in Proceedings of the 27th International Conference on Computational Linguistics, 2018, pp. 3283–3294.

[32] J. Rao, H. He, and J. Lin, "Noise-contrastive estimation for answer selection with deep neural networks," in Proceedings of the 25th ACM International on Conference on Information and Knowledge Management, 2016, pp. 1913–1916.

[33] L. Yang, Q. Ai, J. Guo, and W. B. Croft, "anmm: Ranking short answer texts with attention-based neural matching model," in Proceedings of the 25th ACM international on conference on information and knowledge management, 2016, pp. 287–296.

[34] Y. Tay, L. A. Tuan, and S. C. Hui, "Co-stack residual affinity networks with multi-level attention refinement for matching text sequences," arXiv preprint arXiv:1810.02938, 2018.

[35] H. He, J. Wieting, K. Gimpel, J. Rao, and J. Lin, "UMD-TTIC-UW at SemEval-2016 Task 1: Attention-based multi-perspective convolutional neural networks for textual similarity measurement," in Proceedings of the 10th International Workshop on Semantic Evaluation (SemEval-2016), 2016, pp. 1103–1108.

[36] Y. Shen et al., "Knowledge-aware attentive neural network for ranking question answer pairs," in The 41st International ACM SIGIR Conference on Research & Development in Information Retrieval, 2018, pp. 901–904.

[37] S. V. Moravvej, M. J. M. Kahaki, M. S. Sartakhti, and A. Mirzaei, "A method based on attention mechanism using bidirectional long-short term memory (BLSTM) for question answering," in 2021 29th Iranian Conference on Electrical Engineering (ICEE), IEEE, 2021, pp. 460–464.

[38] Y. Matsubara, T. Vu, and A. Moschitti, "Reranking for efficient transformer-based answer selection," in Proceedings of the 43rd international ACM SIGIR conference on research and development in information retrieval, 2020, pp. 1577–1580.

[39] S. Kim, I. Kang, and N. Kwak, "Semantic sentence matching with densely-connected recurrent and co-attentive information," in Proceedings of the AAAI conference on artificial intelligence, 2019, pp. 6586–6593.

[40] S. J. Mousavirad and H. Ebrahimpour-Komleh, "Human mental search: a new population-based metaheuristic optimization algorithm," Applied Intelligence, vol. 47, pp. 850–887, 2017.

[41] S. V. Moravvej, S. J. Mousavirad, D. Oliva, G. Schaefer, and Z. Sobhaninia, "An improved de algorithm to optimise the learning process of a bert-based plagiarism detection model," in 2022 IEEE Congress on Evolutionary Computation (CEC), IEEE, 2022, pp. 1–7.

[42] S. V. Moravvej, S. J. Mousavirad, D. Oliva, and F. Mohammadi, "A Novel Plagiarism Detection Approach Combining BERT-based Word Embedding, Attention-based LSTMs and an Improved Differential Evolution Algorithm," arXiv preprint arXiv:2305.02374, 2023.

[43] E. M. Voorhees, "The evaluation of question answering systems: Lessons learned from the TREC QA track," in Question Answering: Strategy and Resources Workshop Program, Citeseer, 2002, p. 6.

[44] X. Yao, B. Van Durme, C. Callison-Burch, and P. Clark, "Answer extraction as sequence tagging with tree edit distance," in Proceedings of the 2013 conference of the North American chapter of the association for computational linguistics: human language technologies, 2013, pp. 858–867.

[45] W. Huang, J. Jiang, Q. Qu, and M. Yang, "AILA: A Question Answering System in the Legal Domain.," in IJCAI, 2020, pp. 5258–5260.

[46] Y. Yang, W. Yih, and C. Meek, "Wikiqa: A challenge dataset for open-domain question answering," in Proceedings of the 2015 conference on empirical methods in natural language processing, 2015, pp. 2013–2018.

[47] S. Mirjalili, "Dragonfly algorithm: a new meta-heuristic optimization technique for solving single-objective, discrete, and multi-objective problems," Neural Comput Appl, vol. 27, pp. 1053–1073, 2016.

[48] Y. Shen et al., "Knowledge-aware attentive neural network for ranking question answer pairs," in The 41st International ACM SIGIR Conference on Research & Development in Information Retrieval, 2018, pp. 901–904.

[49] S. Kamath, B. Grau, and Y. Ma, "Predicting and integrating expected answer types into a simple recurrent neural network model for answer sentence selection," Computación y Sistemas, vol. 23, no. 3, pp. 665–673, 2019.

[50] S. V. Moravvej, M. J. M. Kahaki, M. S. Sartakhti, and A. Mirzaei, "A method based on attention mechanism using bidirectional long-short

term memory (BLSTM) for question answering," in 2021 29th Iranian Conference on Electrical Engineering (ICEE), IEEE, 2021, pp. 460–464.

[51] Y. Matsubara, T. Vu, and A. Moschitti, "Reranking for efficient transformer-based answer selection," in Proceedings of the 43rd international ACM SIGIR conference on research and development in information retrieval, 2020, pp. 1577–1580.

[52] S. Kim, I. Kang, and N. Kwak, "Semantic sentence matching with densely-connected recurrent and co-attentive information," in Proceedings of the AAAI conference on artificial intelligence, 2019, pp. 6586–6593.

[53] Y. Song, Q. V. Hu, and L. He, "P-CNN: Enhancing text matching with positional convolutional neural network," Knowl Based Syst, vol. 169, pp. 67–79, 2019.

[54] G. Bao, Y. Wei, X. Sun, and H. Zhang, "Double attention recurrent convolution neural network for answer selection," R Soc Open Sci, vol. 7, no. 5, p. 191517, 2020.

[55] Q. Wang, W. Wu, Y. Qi, and Z. Xin, "Combination of active learning and self-paced learning for deep answer selection with bayesian neural network," in ECAI 2020, IOS Press, 2020, pp. 1587–1594.

[56] W. Huang, Q. Qu, and M. Yang, "Interactive knowledge-enhanced attention network for answer selection," Neural Comput Appl, vol. 32, pp. 11343–11359, 2020.

[57] R. Storn and K. Price, "Differential evolution–a simple and efficient heuristic for global optimization over continuous spaces," Journal of global optimization, vol. 11, pp. 341–359, 1997.

[58] S. Mirjalili, S. M. Mirjalili, and A. Lewis, "Grey wolf optimizer," Advances in engineering software, vol. 69, pp. 46–61, 2014.

[59] X.-S. Yang, "A new metaheuristic bat-inspired algorithm," in Nature inspired cooperative strategies for optimization (NICSO 2010), Springer, 2010, pp. 65–74.

[60] D. Bairathi and D. Gopalani, "Salp swarm algorithm (SSA) for training feed-forward neural networks," in Soft Computing for Problem Solving: SocProS 2017, Volume 1, Springer, 2019, pp. 521–534.

[61] X.-S. Yang and S. Deb, "Cuckoo search via Lévy flights," in 2009 World congress on nature & biologically inspired computing (NaBIC), Ieee, 2009, pp. 210–214.

[62] S. Mirjalili and A. Lewis, "The whale optimization algorithm," Advances in engineering software, vol. 95, pp. 51–67, 2016.

[63] J. Cherian, "Determining the amount of earthquake displacement using differential synthetic aperture radar interferometry (D-InSAR) and satellite images of Sentinel-1 A: A case study of Sarpol-e Zahab city," Advances in Engineering and Intelligence Systems, vol. 1, no. 01, 2022.

[64] G. Hackeling, Mastering Machine Learning with scikit-learn. Packt Publishing Ltd, 2017.

[65] S. Sonkar, A. E. Waters, and R. G. Baraniuk, "Attention word embedding," arXiv preprint arXiv:2006.00988, 2020.

[66] J. Pennington, R. Socher, and C. D. Manning, "Glove: Global vectors for word representation," in Proceedings of the 2014 conference on empirical methods in natural language processing (EMNLP), 2014, pp. 1532–1543.

[67] B. Athiwaratkun, A. G. Wilson, and A. Anandkumar, "Probabilistic fasttext for multi-sense word embeddings," arXiv preprint arXiv:1806.02901, 2018.

# Evaluation Method of Physical Education Students' Mental Health based on Multi-source and Heterogeneous Data

YongCheng WU

Anhui Technical College of Mechanical and Electrical Engineering, Anhui Wuhu, 241000, China

*Abstract*—To enhance the ability to evaluate the mental health status of physical education students, a method of evaluating the mental well-being state of physical education students based on multi-source heterogeneous data mining is proposed. A fuzzy information detection model of multi-source heterogeneous data on the mental health status of physical education students is constructed, with four factors as dependent variables: compulsion, interpersonal sensitivity, hostility, and depression. Combined with the hierarchical index parameter detection and analysis method, the statistical analysis of multi-source heterogeneous info is accomplished. Based on the factor extraction outcomes of multi-source heterogeneous info, combined with the subspace heterogeneous fusion method, an estimated parameter feature clustering model is established. Combining the results of characteristic distributed clustering and linear regression analysis, the psychological well-being state evaluation of physical education students is realized. The results of empirical analysis show that this method has higher accuracy and better feature resolution in the evaluation of the mental well-being state of physical education students, which improves the reliability and confidence level of the assessment of the mental well-being status of physical education students.

*Keywords—Multi-source heterogeneous data; sports major; students; mental health; assess the situation; confidence level; linear regression analysis*

## I. INTRODUCTION

Based on the analysis of the rules of school physical education, the physical education major teaches the basic theory, knowledge, and skills of physical education major, and trains students who have talents and expertise in the field of education, can engage in physical education teaching, extracurricular sports activities, extracurricular sports training, and competitions, and can conduct scientific research, management, and guidance. There are obvious differences between physical education majors and other majors in the ways of attending classes, practicing after class, and conducting experiments and different training methods will develop students' different ways of thinking and attitudes toward life [1]. For example, "Research on Personality Differences between Physical Education Majors and Students of Science and Liberal Arts" indicates that there are great disparities in personality among physical education majors and students of other training methods. The research on the differences in personality and thinking mode between domestic liberal arts students and science students also shows that there are significant differences in personality and thinking mode

among students cultivated under different training modes. "Combined with the research, it is found that because of the different training methods, the mental well-being status of university students majoring in physical education will be different from that of other majors [2]–[4]. Therefore, knowing the mental health status of university students majoring in physical education and carrying out targeted mental health education are also beneficial to better professional talents who meet the training objectives of physical education [5].

Chinese scholars have summarized mental health. Broadly speaking, mental well-being implies an effective, satisfying and stable mental status. In a narrow sense, mental well-being implies the full and consonant procedure of individuals' primary mental actions, that is, the complete and coordinated knowledge, emotion, will, behavior, and personality that can adjust to the community and keep pace with the community. By studying the evaluation model of physical, intellectual, and emotional development of physical education students' mental health, combined with multi-source heterogeneous data fusion analysis of physical education learners' psychological wellness performance, the evaluation level of physical education learners' psychological wellness can be improved, and the study on related calculation methods of physical education students' mental health has attracted great attention [6].

In response to the above issues, this article proposes a method for evaluating the mental health status of sports major students based on multi-source heterogeneous data mining. This method utilizes a fuzzy information detection model and a hierarchical indicator parameter detection analysis method to evaluate four factors: compulsion, interpersonal sensitivity, hostility, and depression. Establish an estimation parameter feature clustering model through multi-source heterogeneous data feature extraction and subspace heterogeneous fusion methods. By combining the results of feature distributed clustering and linear regression analysis, the evaluation of the psychological health status of sports major students is achieved. Empirical analysis shows that this method has good performance in evaluating accuracy, feature resolution, and reliability.

## II. RELATED WORKS

The study on the evaluation of physical education students' mental well-being is on the basis of the reliability fusion and cluster analysis detection of data. Joined with the correlation feature detection and extraction way, the evaluation and feature fusion of physical education students' mental health can

improve the balance of multi-source heterogeneous data output of physical education students' mental health [7]. In the traditional method, there are mainly fuzzy aggregation scheduling methods, PID scheduling methods and self-adaptive equilibrium scheduling methods for the evaluation of physical education learners' psychological wellness under the coordinated improvement of physical intelligence and emotion. The author in [8] used symptom checklist to test 15392 freshmen from 2013 to 2019, with P values <0.001 However, this method cannot fully consider the factors of gender, nationality, and professional category when carrying out psychological counselling. The author in [9] proposed an automatic evaluation method of College Students' mental health based on multimodal data fusion calculation Build a multimodal psychological assessment data set (ja-ipad) model to improve students' psychological files, accurately intervene in students' psychology, and optimize mental health services to provide decision-making basis and technical support, but this method has problems of poor anti-interference and weak feature resolution in the procedure of College Students' mental well-being assessment.

## III. MULTI-SOURCE HETEROGENEOUS DATA MINING THEORY

In the procedure of informatization construction, because of the stage, technicality, and other economic and human features of the construction and implementation of data management systems of various business systems, a huge amount of business info with several storage ways has been accumulated in the development process, including different data management systems[10], [11]. From simple file databases to complex system databases, they constitute multi-source heterogeneous info. Multi-source data fusion is to combine several info data, capture the specification of distinct info origins, and then extracts unified, better and richer data than single info. Multi-source heterogeneous data comes from multiple data sources, including data sets collected by different database systems and different devices in their work. Heterogeneous data includes many types of structured data, semi-structured data, and unstructured data. There is no uniform standard in the formation of different types of data, which leads to the "heterogeneous" characteristics of data. According to the requirements, the data are calculated and the data model is automatically established, which effectively reduces the burden of statistical work and improves the efficiency of data analysis.

## IV. DATA ANALYSIS AND STATISTICAL ANALYSIS ON EVALUATION OF PHYSICAL EDUCATION STUDENTS' MENTAL HEALTH

### A. Spatial Cluster Distribution Structure of Evaluation Data of Physical Education Students' Mental Wellness

Aiming to conceive the assessment of physical education students' mental wellness under the coordinated development of physical intelligence and emotion, a fuzzy information detection model of multi-source heterogeneous data of physical education learners' psychological wellness under the

coordinated improvement of physical intelligence and emotion is constructed[12], [13]. According to the SCL-90 questionnaire, among various factors, if the score of a certain factor is more than or equal to 3, the subject may have a moderate degree of mental health problems, while the score of any one of the 10 symptom factors ≥2 indicates. If any factor scores 2.2 and < 3, the subjects can be considered to be in a sub-health psychological state. Less than or equal to 2 has no mental health problems. According to the survey, the number of students with medium or above mental disorders accounted for 4.69% of the total number, which was 13. The amount of students in the sub-health state is 86, accounting for 31.05% of the whole. The amount of students in mental wellness is 178, accounting for 64.26% of the whole amount. The fuzzy correlation analysis of multi-source heterogeneous data of physical education learners' psychological well-being under the coordinated improvement of physical intelligence and emotion is accomplished using the feature extraction algorithm of high-order statistics, and the fuzzy decision figure of mining multi-source heterogeneous data of physical education learners' psychological well-being under the coordinated improvement of physical intelligence and emotion is established. The fuzzy information cluster analysis of multi-source heterogeneous data of physical education learners' psychological wellness under the coordinated improvement of physical intelligence and emotion is carried out, and the distributed detection model of multi-source heterogeneous data of physical education learners' psychological well-being under the coordinated improvement of physical intelligence and emotion is established[14] . The statistical spatial information category distribution of multi-source heterogeneous data of physical education trainees' psychological well-being under the coordinated improvement of physical intelligence and emotion is shown in Fig 1.

Based on the statistical spatial information category dispensation pattern of multi-source heterogeneous data of physical education trainees' psychological wellness under the coordinated improvement of physical intelligence and emotion shown in Fig 1, the attribute scheduling of multi-source heterogeneous data of physical education trainees' psychological well-being under the coordinated improvement of physical intelligence and emotion is accomplished using pointer fusion indicator way, and the spatial coordinate block distribution model of multi-source heterogeneous data of physical education trainees' psychological wellness under the coordinated improvement of physical intelligence and emotion is established[15]. Improve the statistical analysis and mining ability of multi-source heterogeneous data of physical education trainees' psychological well-being under the coordinated improvement of physical intelligence and emotion and build a pointer scheduling model of multi-source heterogeneous data of physical education trainees' psychological wellness under the coordinated improvement of physical intelligence and emotion as presented in Fig 2.

Based on the mental wellness state evaluation model of physical education students shown in Fig 2, the fuzzy correlation of the mental wellness state evaluation data of physical education students is analyzed.
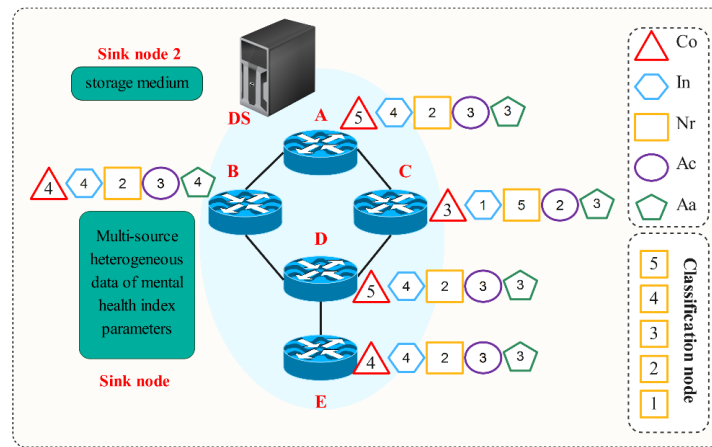
Fig. 1.   Statistical spatial information category distribution of mental health evaluation data of physical education majors.
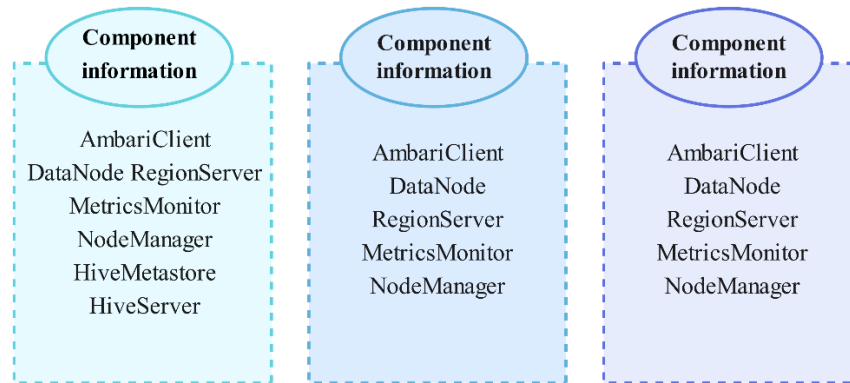


Fig. 2.   Evaluation model of the mental wellness status of physical education majors under the coordinated improvement of physical intelligence and emotion.

*B. Fuzzy Correlation Analysis of the Evaluation Data of Physical Education Students' Mental Health Under the Coordinated Development of Physical Intelligence and Emotion*

The fuzzy correlation analysis of multi-source heterogeneous data of physical education learners' psychological well-being under the coordinated improvement of physical intelligence and emotion is accomplished using the feature extraction way of high-order statistics[16]–[18]. The outcome autocorrelation factor accordant type of multi-source heterogeneous info of physical education learners' psychological well-being under the coordinated improvement of physical intelligence and emotion is constructed, and the fuzzy clustering feature coefficient of multi-source heterogeneous data of physical education learners' psychological well-being under the coordinated improvement of physical intelligence and emotion is calculated[19]–[21], which is defined as:

$$A_j(L+1) = \frac{1}{n_j} \sum_{i=1}^{k} X_i^j \quad j = 1,2,\ldots,k \qquad (1)$$

Wherein, $n_j$ is a multi-source feature of the physical education students' mental health status, $X_i^j$ is a multi-source heterogeneous spatial distribution set of physical education students' mental health status, and $k$ is an embedded dimension. By analyzing the output difference features of multi-source heterogeneous data of physical education learners'

psychological well-being status under the coordinated improvement of physical intelligence and emotion, the fuzzy cluster analysis of multi-source heterogeneous data of physical education learners' psychological well-being status under the coordinated improvement of physical intelligence and emotion is carried out by using high-order statistical analysis method, and the discrete scheduling formula of multi-source heterogeneous data of physical education learners' psychological well-being status under the coordinated improvement of physical intelligence and emotion is defined as[22], [23]:

$$C(l) = \sum_{j=1}^{k} \sum_{k=1}^{n_j} (||x_k^j - A_j(L)||)^2 \qquad (2)$$

Wherein $x(t)$ is the fuzziness of multi-source heterogeneous data sets of physical education learners' psychological well-being under the coordinated improvement of physical intelligence and emotion and $A_j(L)$ represents the similarity characteristic quantity. Fuzzy data clustering and distributed discrete scheduling ways are adopted to control the output reliability of multi-source heterogeneous data of physical education learners' psychological well-being under the coordinated improvement of physical intelligence and emotion. Establishing the attribute cluster distribution model of multi-source heterogeneous data of physical education learners' psychological well-being under the coordinated improvement of physical intelligence and emotion can realize the statistical detection of multi-source heterogeneous data sets of physical education learners' psychological well-being under the

coordinated improvement of physical intelligence and emotion[24], [25]. Combining with the similarity feature analysis method, the multi-source heterogeneous data mining feature quantity of physical education learners' psychological well-being under the coordinated improvement of physical intelligence and emotion is established, and the residual distribution matrix of multi-source heterogeneous data of physical education learners' psychological well-being under the coordinated improvement of physical intelligence and emotion is as follows:

$$D(x_i, A_j(L)) = min\{ D(x_i, A_j(L)) \} \qquad (3)$$

Wherein, $D(x_i, A_j(L))$ is the global weighted value of the evaluation of physical education students' mental health under the coordinated development of physical intelligence and emotion at the $i$ point. A fuzzy information detection model of multi-source heterogeneous data of physical education learners' psychological well-being under the coordinated improvement of physical intelligence and emotion is constructed. The fuzzy correlation analysis of multi-source heterogeneous data of physical education learners' psychological well-being under the coordinated improvement of physical intelligence and emotion is accomplished using a high-order statistical detail mining way, and data mining and fuzzy clustering are carried out according to the feature extraction results.

## V. EVALUATION AND OPTIMIZATION OF PHYSICAL EDUCATION STUDENTS' MENTAL HEALTH STATUS

### A. Multi-source Heterogeneous Data Mining of Physical Education Students' Mental Health Under the Coordinated Development of Physical Intelligence and Emotion

Based on the fuzzy information detection model of multi-source heterogeneous data of physical education learners' psychological well-being under the coordinated improvement of physical intelligence and emotion, and the fuzzy correlation analysis of multi-source heterogeneous data of physical education learners' psychological well-being under the coordinated improvement of physical intelligence and emotion by using high-order statistical feature extraction method, the communication link data mining is carried out. This paper puts forward an evaluation method of physical education learners' psychological well-being under the coordinated improvement of physical intelligence and emotion according to multi-origin heterogeneous info mining. The outcome autocorrelation factor accordant type of multi-source heterogeneous info of physical education learners' psychological well-being under the coordinated improvement of physical intelligence and emotion is formed, and the numerical evaluation of multi-source heterogeneous info of physical education learners' psychological well-being under the coordinated improvement of physical intelligence and emotion is carried out by combining the hierarchical index parameter detection and analysis method. By adopting the multi-source heterogeneous data mining algorithm, the feature distribution set of data sampling node I at time T is expressed as $V = \{v_{ij} | i = 1,2,\cdots,c, j = 1,2,\cdots,s\}$, $t$ is the offset characteristic quantity of multi-source heterogeneous data of physical education learners' psychological well-being under the coordinated improvement of physical intelligence and emotion, and S is the

weighting coefficient of evaluation of physical education learners' psychological well-being under the coordinated improvement of physical intelligence and emotion. Combining the semantic factor evaluation way with a fuzzy semantic factor rule set for evaluation of physical education learners' psychological well-being under the coordinated improvement of physical intelligence and emotion is formed, and the adaptive weighting coefficient of multi-source heterogeneous data of physical education learners' psychological well-being under the coordinated improvement of physical intelligence and emotion is as follows[26]:

$$H(t) = \overset{\wedge}{h}(t) * p(t) * p(-t)$$
$$= (\sum_{i=1}^{M} h'_i(t) * h_i(-t)) * p(t) * p(-t) \qquad (4)$$

Wherein, $\overset{\wedge}{h}(t)$ is the regression analysis value, $p(t)$ is the dynamic fitting parameter, $h'_i(t)$ is the distribution function of transmission reliability, and $max_l Freq_{i,j}$ is the residual specification amount of physical education students' mental wellness analysis and optimization under the coordinated development of physical intelligence and emotion among $d_j$. $k_i$ is defined as the fuzziness of multi-source heterogeneous data mining of physical education learners' psychological well-being under the coordinated improvement of physical intelligence and emotion;

$$p_{ri}(t) = p(t) * h_i(t) + n_{pi}(t) \qquad (5)$$

$$S_{ri}(t) = S(t) * h'_i(t) + n_{si}(t) \qquad (6)$$

Wherein, $S(t)$ and $h'_i(t)$ are the fuzzy rule features of the physical education students' mental health evaluation under the coordinated development of physical intelligence and emotion and $n_{si}(t)$ is the interference item of multi-source heterogeneous data mining. The fuzzy clustering way is attained to optimize the shortest path of physical education students' mental wellness evaluation under the coordinated development of physical intelligence and emotion[27], and its calculation formula is:

$$r_i'(t) = S_{ri}(t) * p_{ri}(-t)$$
$$= S(t) * p(-t) * h'_i(t) * h_i(-t) + n_{1i}(t) \qquad (7)$$

Wherein, $S_{ri}(t)$ is the joint matching coefficient, $S(t)$ is the similarity characteristic quantity, and $n_{1i}(t)$ is the dynamic interference component. Using the statistical information analysis method, this paper establishes the correlation distribution set of multi-source heterogeneous data of physical education students' mental health under the coordinated development of physical intelligence and emotion. On this basis, the spherical test of KMO and Bartlett is carried out on the scale (the test results show whether the scale can be used for exploratory feature evaluation), and then the exploratory feature evaluation is accomplished. Generally speaking, when the KMO test value is above 0.8, it is suitable for exploratory factor analysis, and Bartlett's spherical test value needs to reach a significant level, that is Sig<0.05, then exploratory factor analysis can be carried out on this scale. Therefore, the spherical test of KMO and Bartlett is required for the pre-test

psychological resilience scale, and the experiment outcomes are presented in [28], [29] (12 direction scoring questions have been preprocessed). The fuzzy data factor evaluation way is attained to perceive the outcome autocorrelation factor accordant of multi-source heterogeneous data of physical education students' mental health under the coordinated development of physical intelligence and emotion and to improve the ability of mining multi-source heterogeneous data of physical education students' mental health under the coordinated development of physical intelligence and emotion.

### B. Evaluation of Mental Health Status of Students Majoring in Physical Education Under the Coordinated Development of Intelligence and Emotion

Based on the multi-source cluster analysis method of the split grid, a multi-source heterogeneous data mining model of the physical education students' mental health status under the coordinated development of physical intelligence and emotion is established. The feature extraction results are evaluated by the hierarchical index parameter detection method. The global variables are set, and the fuzzy partition coefficient of physical education students' mental health status evaluation under the coordinated development of physical intelligence and emotion is established as follows:

$$V_i = \frac{\sum_{k=1}^m (\mu_{ik})^m x_k}{\sum_{k=1}^n (\mu_{ik})^m} \qquad (8)$$

Where, $\mu_{ik}$ represents the median of mental wellness evaluation of physical education students under the coordinated development of physical intelligence and emotion, $m$ is the lower bound of mental wellness evaluation of physical education students under the coordinated development of physical intelligence and emotion, and it is the median of multi-source heterogeneous data of mental wellness of physical education students under the coordinated development of physical intelligence and emotion, and n represents the minimum statistical characteristic quantity of multi-source heterogeneous data of mental wellness of physical education students under the coordinated development of physical intelligence and emotion in all dimensions. Based on the detail mining outcomes of multi-source heterogeneous info of physical education students' mental health under the coordinated development of physical intelligence and emotion, the hierarchical index parameter detection method is adopted to evaluate the mental health of physical education students under the coordinated development of physical intelligence and emotion. The great info extraction model is shown below:

$$P_u = \frac{\left| \sum_1^{N_R} s(i,t) \right|}{V} = \frac{N_R}{V} \qquad (9)$$

Wherein, $s(i,t)$ is a linear fitting parameter of multi-source heterogeneous data of physical education students' mental health status, $N_R$ is a multi-source decision function, and $V$ is KMO test value. Under the decision tree model of physical education students' mental health evaluation data distribution under the coordinated development of physical intelligence and emotion, this paper adopts a multi-source heterogeneous data mining algorithm to carry out self-adaptive optimization in the procedure of physical education students' mental wellness evaluation under the coordinated development of physical

intelligence and emotion, with four factors of compulsion, interpersonal sensitivity, hostility and depression as dependent variables. Combined with the hierarchical index parameter detection and analysis method, this paper makes a statistical analysis of multi-source heterogeneous data on physical education students' mental health under the coordinated development of physical intelligence and emotion. Based on the detail mining outcomes of multi-source heterogeneous data of physical education students' mental health, the analysis of physical education students' mental wellness is perceived.

## VI. SIMULATION AND RESULT ANALYSIS

Aiming to confirm the applying performance of this way in the analysis of physical education students' mental wellness, a simulation examination evaluation was applied. In order to ensure the effectiveness of the experiment, the experimental parameters of this article are set as follows:

*1) Fuzzy information detection model:* clustering number 4.

*2) Detection* and analysis method for hierarchical index parameters: significance level 0.05.

*3) Feature* extraction and subspace heterogeneous fusion methods: Dimension 10 of principal component analysis (PCA), hyperparameter lambda=0.5 of subspace fusion methods.

Among them, the comparative method uses the corresponding parameters used in its experiment, and will not be introduced in detail here.

Matlab was used for the algorithm processing of the analysis of physical education students' mental wellness, and the number of nodes for multi-source heterogeneous data sampling of the physical education students' mental well-being was set to 400. The Sink root node of the physical education students' mental well-being evaluation is 35, the Sink source node number of the physical education students' mental well-being evaluation is 6, the length of multi-source heterogeneous data sampling of physical education learners' psychological well-being under the coordinated improvement of physical intelligence and emotion is 3000, and the distribution characteristic resolution of association rules of physical education students' mental health evaluation is 34Bps/s, The sampling frequency of multi-source heterogeneous statistical features for the analysis of physical education students' mental well-being is 24Hz, and the sampling frequency of autocorrelation features is 46Hz. Based on the earlier principles, the evaluation of physical education students' mental wellness under the coordinated development of physical intelligence and emotion is carried out. Same to the exploratory factor analysis method used in the preliminary investigation, the test results of KMO and Bartl ett are shown below. Cronbach's Alpha Reliability Analysis Table, a positive scale of psychological toughness, is constructed. The KMO value of this scale is 0.915, and Bartlett's test value is 0.000 (<0.05). This scale is very suitable for factor analysis. By using principal component analysis and tilt rotation method, 10 common factors were extracted, the maximum convergence iteration times were 25, and the cumulative contribution rate reached 60.00% for observation. Factor analysis one by one

eliminated KL3, KL10, KL29, KL47, KL17, KL18, KL51, KL57, KL6, KL15, KL34 and KL. After 15 times of factor extraction, the load value of each factor is above 0.4, and the cumulative variance is 60.00%, that is, the total explanation rate of the factors is 60.00%, which has a high explanation rate. The reliability of 60 items in 602 questionnaires of middle school students' mental health scale was analyzed, and Cronbach's Alpha coefficient was 0.929, a> 0.85, which indicated that the reliability of the formal survey scale was good.

Combined with the results of the exploratory factor analysis of the formal psychological resilience scale, the confirmatory feature evaluation was applied with statistical software AMOS 20.0, the path significance was estimated by maximum likelihood estimation, and the fitting degree of the structural equation model was tested. The model was modified by combining factor load and model fitting index, and four factors, compulsion, interpersonal sensitivity, hostility, and depression, were taken as dependent variables. The distribution of multi-source heterogeneous data on physical education learners' psychological well-being under the coordinated improvement of physical intelligence and emotion was obtained as shown in Fig. 3.

The analysis shows that the factor loads of C15, C16, and C17 are negative, and the factor loads of C19 and C22 are less than 0.4. The load of the C18 factor in interpersonal assistance is negative, so there is only one factor in the dimension of positive cognition, so the dimension of positive cognition is deleted.

Fig. 3 shows that there are three impulse response waves in the obsessive-compulsive mental health state, two impulse waves in the interpersonal sensitive state and hostile state, and two shock waves in the depression state. The pattern in this article is able to precisely detect the multi-source heterogeneous data feature points of physical education majors' mental health state. At the same time, it is found that the fitting degree of the first model is not good in the absolute fitting index and relative fitting index of the model fitness test.

According to the correction index given by AMOS software, the model is modified by the residual correction method, with four factors of compulsion, interpersonal sensitivity, hostility, and depression as dependent variables. The final verification path correction result of the psychological resilience scale is shown in Fig. 4.



Force

Interpersonal sensitivity

(a) Compulsion, interpersonal sensitivity.



Hostile

Depression

(b) Hostility and depression.
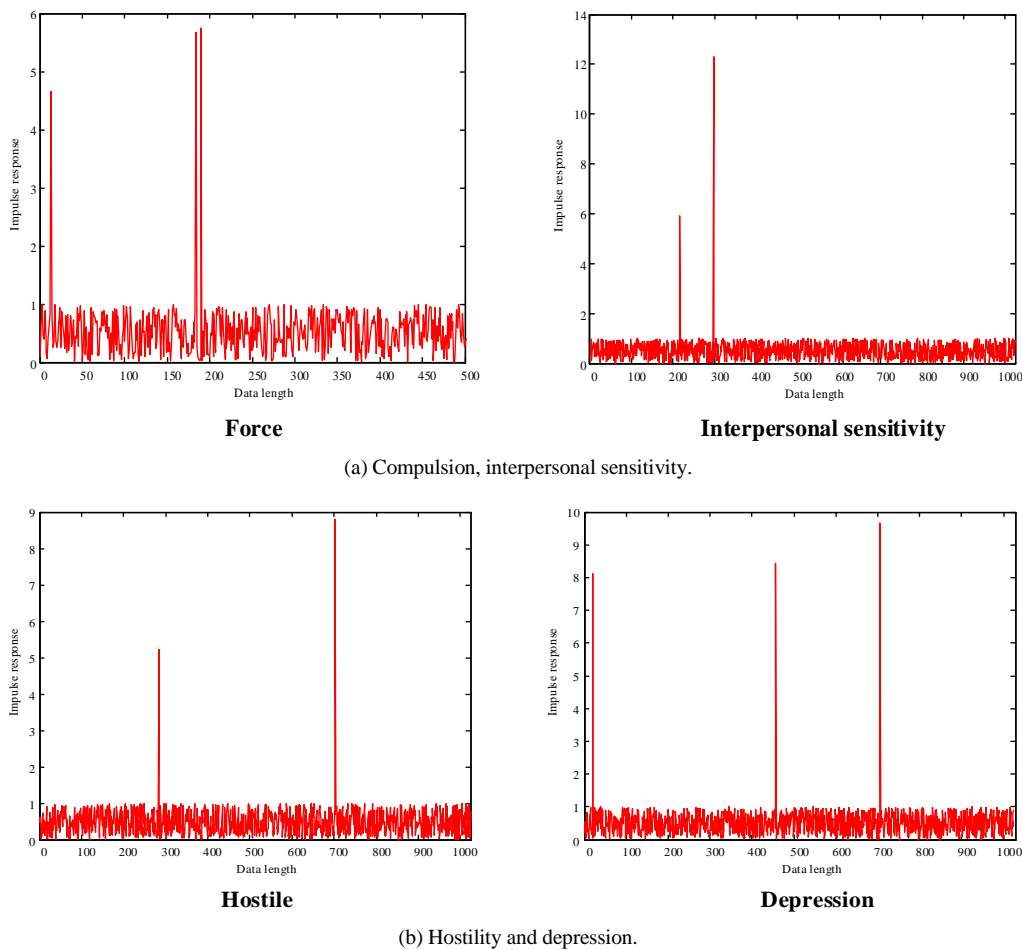
Fig. 3. Multi-source heterogeneous data distribution of physical education students' mental health status.
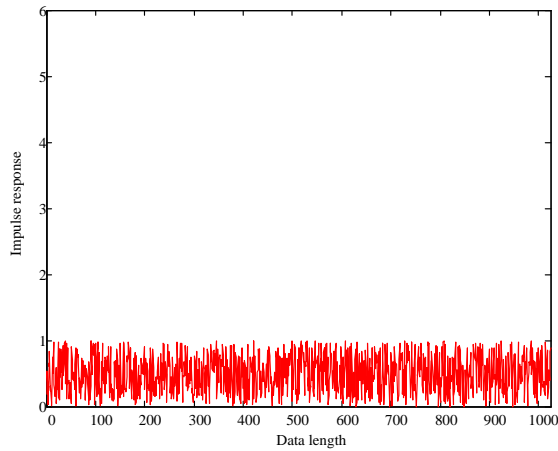
Fig. 4.    Validation path correction results of the psychological resilience scale.

According to the analysis of Fig. 4, the multi-source heterogeneous mining is realized by this method, which reduces the risk of university students' mental well-being, suppresses the impulse wave of mental wellness risk state, establishes the regression analysis model of multi-source heterogeneous data of physical education students' mental health under the coordinated development of physical intelligence and emotion, and extracts the statistical characteristic quantity of multi-source heterogeneous data of physical education students' mental health under the coordinated development of physical intelligence and emotion. Based on the factor mining outcomes of multi-source heterogeneous info of physical education students' mental health, the health assessment is realized. It is concluded that all fitting indexes of the psychological resilience scale have reached an acceptable or good level. It proves that the structure of the revised psychological resilience scale has reached a stable state and is suitable for later research and analysis. The path coefficients of D12 and D23 in the obsessive-compulsive dimension, D4, D45, and D59 in the interpersonal tension and sensitivity dimension, D36 in the learning stress dimension, and D1 and D9 in the maladjustment dimension are all less than 0.4. Therefore, these items are deleted and combined with the model fitting index, it is found that the first Chinese middle school students' mental health scale model is not good. This way is able to effectively perceive the multi-source heterogeneous data mining of physical education students' mental health, improve the clustering ability and output balance of the info, and test the accuracy of several ways in evaluating physical education students' mental health. The comparison results are shown in Table I. From the analysis of Table I, it is known that the accuracy of this method in evaluating physical education students' mental health is high.

This algorithm is for analyzing the abnormal risk probability of mental wellness of physical education students in the 2019 academic year. The statistical results are shown in Fig. 5.

Through the simulation results in Fig. 5, it can be seen that the obtained probability coefficient is highly compatible with the actual probability coefficient. Using this algorithm can effectively evaluate the normal probability and abnormal

probability of mental health of sports students in the 2019 academic year, which shows that this algorithm can effectively evaluate the mental health status of sports students.

On this basis, by comparing the methods of [5] and [7], the calculation complexity of the proposed algorithm is counted (Table I). The shorter the time of the algorithm, the lower is the calculation complexity. Therefore, the experiment is carried out with the evaluation time as the test index, and the experimental results are shown in Fig. 6.

As shown in Fig. 6, under the same conditions, the proposed method takes the shortest time, indicating that the proposed method has the lowest computational complexity, the strongest operability, and high practical applicability.

TABLE I.    COMPARISON OF EVALUATION ACCURACY OF THE MENTAL HEALTH STATUS OF STUDENTS MAJORING IN PHYSICAL EDUCATION UNDER THE COORDINATED DEVELOPMENT OF PHYSICAL INTELLIGENCE AND EMOTION

| Iterations | Methods of this paper | Reference [5] | Reference [7] |
|---|---|---|---|
| 20 | 0.976 | 0.854 | 0.887 |
| 40 | 0.978 | 0.877 | 0.892 |
| 60 | 0.999 | 0.924 | 0.925 |
| 80 | 1 | 0.946 | 0.943 |
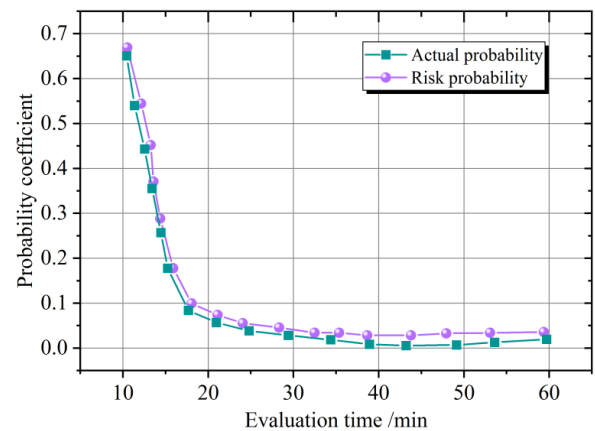


Fig. 5.    Probability assessment results of abnormal mental health risk.
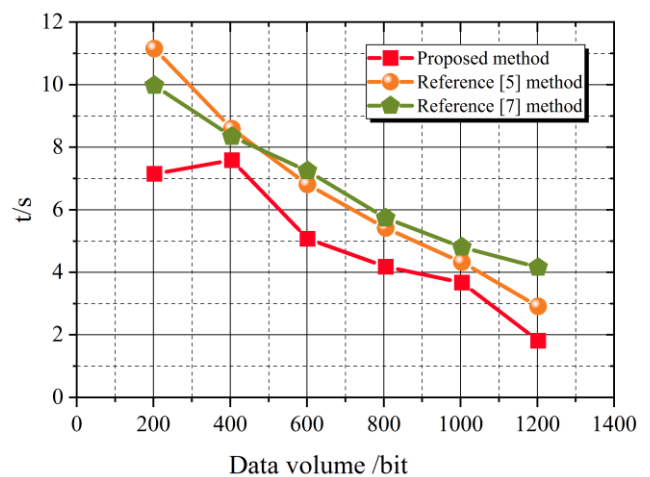


Fig. 6.    Comparison of evaluation time of different methods.

## VII. Discussion

Based on the above research results, it can be concluded that this method provides a more comprehensive perspective for the evaluation of the mental health status of sports majors by integrating data from different sources and types.

In reality, the mental health issues of sports major students are of great concern. Using multi-source heterogeneous data for evaluation can better capture multidimensional information of individuals and identify potential mental health risk factors. In addition, the introduction of fuzzy information detection models, hierarchical index parameter detection and analysis methods, feature extraction, and subspace heterogeneous fusion techniques make the evaluation indicators more accurate and reliable.

However, there are still some challenges and room for improvement in further applications. The effective integration and processing of different types of data is a complex task that requires further optimization and exploration of methods and models suitable for different data types. In future research, it is recommended to further expand the scope of multi-source heterogeneous data evaluation and strengthen research on data preprocessing, feature selection, and model optimization.

## VIII. Conclusions

In this article, an evaluation method of physical education students' mental health based on multi-source heterogeneous data mining is proposed. The output autocorrelation characteristic matching model of multi-source heterogeneous data of physical education students' mental health under the coordinated development of physical intelligence and emotion is constructed, and the statistical analysis of multi-source heterogeneous data of physical education students' mental health under the coordinated development of physical intelligence and emotion is carried out by combining the hierarchical index parameter detection and analysis method, and the fuzzy segmentation model of evaluation of physical education students' mental health under the coordinated development of physical intelligence and emotion is established. Multi-source heterogeneous data mining algorithm is used to self-adaptively optimize the evaluation process of physical education students' mental health under the coordinated development of physical intelligence and emotion, so as to realize the evaluation of physical education students' mental health under the coordinated development of physical intelligence and emotion. The analysis shows that this method has good balance and high accuracy in scheduling multi-source heterogeneous data of physical education students' mental health under the coordinated development of physical intelligence and emotion. Through empirical analysis, the following conclusions are also drawn:

First, the overall situation of physical exercise of students majoring in physical education is good. The overall average of psychological resilience is high, and the overall average of mental health is high.

Secondly, the physical exercise behavior of students majoring in physical education shows significant gender and grade differences at the overall level; there are significant grade differences in its sub-dimensions, and there are significant gender differences in the intensity and time of physical exercise.

Thirdly, there are significant grade differences in the overall level of physical education major students' psychological resilience and its sub-dimensions; there are significant gender differences in their sub-dimension goal concentration and emotional control.

Fourthly, there are significant gender and grade differences in physical education students' mental health as a whole and its sub-dimensions; there are significant differences in their sub-dimension maladjustment in the only child.

Although this study has achieved good research results, there may be biases in the selection of samples in the study, resulting in inaccurate evaluation results or lack of widespread applicability. Therefore, further consideration will be given to the randomness and representativeness of sample selection in the next step of research.

## Data Availability

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

## Conflicts of Interest

The authors declared that they have no conflicts of interest regarding this work.

## Funding

## References

[1] L. H. Gunn, E. Ter Horst, T. Markossian, and G. Molina, "Associations between majors of graduating seniors and average SATs of incoming students within higher education in the US," Heliyon, vol. 6, no. 5, 2020.

[2] D. H. Lu, J. A. Dopheide, D. Wang, J. K. Jeffrey, and S. Chen, "Collaboration between child and adolescent psychiatrists and mental health pharmacists to improve treatment outcomes," Child and Adolescent Psychiatric Clinics, vol. 30, no. 4, pp. 797–808, 2021.

[3] C. Sun, C. K. H. Hon, K. A. Way, N. L. Jimmieson, and B. Xia, "The relationship between psychosocial hazards and mental health in the construction industry: A meta-analysis," Saf Sci, vol. 145, p. 105485, 2022.

[4] J. Tabler, R. M. Schmitz, J. M. Nagata, and C. Geist, "Self-perceived gender expression, discrimination, and mental health disparities in adulthood," SSM-Mental Health, vol. 1, p. 100020, 2021.

[5] Z. Guo and Y. Zhang, "Study on the interactive factors between physical exercise and mental health promotion of teenagers," J Healthc Eng, vol. 2022, 2022.

[6] C. Fossati et al., "Physical exercise and mental health: The routes of a reciprocal relation," Int J Environ Res Public Health, vol. 18, no. 23, p. 12364, 2021.

[7] Y. Nie et al., "Association between physical exercise and mental health during the COVID-19 outbreak in China: a nationwide cross-sectional study," Front Psychiatry, vol. 12, p. 722448, 2021.

[8] P. Zhao, "Investigation and Analysis on the Mental Health Status of College Students," in 2022 3rd International Conference on Big Data and Informatization Education (ICBDIE 2022), Atlantis Press, 2022, pp. 966–973.

[9]  X. Zhou, L. Liu, Y. Chen, J. Hong, and L. U. Xiao, "Research on design and application of an automatic assessment model for college students' mental health based on multimodal data fusion," E-education Research, vol. 42, no. 8, pp. 72–78, 2021.

[10] D. Kleszczewska, J. Mazur, and J. Siedlecka, "Family, school and neighborhood factors moderating the relationship between physical activity and some aspects of mental health in adolescents," Int J Occup Med Environ Health, vol. 32, no. 4, 2019.

[11] W. Zhang et al., "A landing impact simulation test method for lunar lander," in Journal of Physics: Conference Series, IOP Publishing, 2021, p. 012017.

[12] X. Chen et al., "Visual analysis of multi-source college students' mental health questionnaire data," Journal of Computer Aided Design and Graphics, vol. 32, no. 2, pp. 12–24, 2020.

[13] D. Sánchez-Oliva, J. J. Pulido-González, F. M. Leo, I. González-Ponce, and T. García-Calvo, "Effects of an intervention with teachers in the physical education context: A Self-Determination Theory approach," PLoS One, vol. 12, no. 12, p. e0189986, 2017.

[14] W. Xinbo, Y. A. O. Li, Z. Xiaojie, S. Xiaosong, S. H. U. Meiling, and L. I. U. Shuang, "Comprehensive grading of psychological crisis in children and adolescents," 北京师范大学学报 (自然科学版), vol. 57, no. 4, pp. 458–465, 2021.

[15] Q. He, H.-W. Hao, and X.-C. Yin, "Keyword extraction based on multi-feature fusion for Chinese web pages," in Proceedings of the 2011 2nd International Congress on Computer Applications and Computational Science: Volume 1, Springer, 2012, pp. 119–124.

[16] D. Kristomo, R. Hidayat, I. Soesanti, and A. Kusjani, "Heart sound feature extraction and classification using autoregressive power spectral density (AR-PSD) and statistics features," in AIP conference proceedings, AIP Publishing, 2016.

[17] S. Zhang, Y. Wang, S. He, and Z. Jiang, "Bearing fault diagnosis based on variational mode decomposition and total variation denoising," Meas Sci Technol, vol. 27, no. 7, p. 075101, 2016.

[18] Q. Zhao, C. F. Caiafa, A. Cichocki, L. Zhang, and A. H. Phan, "Slice oriented tensor decomposition of EEG data for feature extraction in space, frequency and time domains," in Neural Information Processing: 16th International Conference, ICONIP 2009, Bangkok, Thailand, December 1-5, 2009, Proceedings, Part I 16, Springer, 2009, pp. 221–228.

[19] C. Pan, X. Jia, J. Li, and X. Gao, "Adaptive edge preserving maps in Markov random fields for hyperspectral image classification," IEEE Transactions on Geoscience and Remote Sensing, vol. 59, no. 10, pp. 8568–8583, 2020.

[20] M. XIAO, L. ZHANG, X. ZHANG, and Y. HU, "An improved fuzzy clustering method for interval uncertain data," 电子与信息学报, vol. 42, no. 8, pp. 1968–1974, 2020.

[21] R.-Z. Zhao and Z.-J. Sun, "Method of fault identification based on fusion of CEEMD_MPE and GK fuzzy clustering," 2020.

[22] Y. Deng, "Finite difference numerical simulations of acoustic fields with MPI and GPUS," in Proceedings of the 2014 Symposium on Piezoelectricity, Acoustic Waves, and Device Applications, IEEE, 2014, pp. 302–305.

[23] H. Wang, W. Mao, and L. Eriksson, "Benchmark study of five optimization algorithms for weather routing," in International Conference on Offshore Mechanics and Arctic Engineering, American Society of Mechanical Engineers, 2017, p. V07BT06A023.

[24] S. Rye and E. Aktas, "A Multi-Attribute Decision Support System for Allocation of Humanitarian Cluster Resources Based on Decision Makers' Perspective," Sustainability, vol. 14, no. 20, p. 13423, 2022.

[25] Y. Shaobo, W. Qinghe, W. Xiao-chun, and X. L. De, "Cloud Information Storage Encryption Based on Fuzzy Clustering Algorithm [J]," Computer simulation, vol. 37, no. 3, pp. 449–452, 2020.

[26] F. Yihao, W. Jun, X. Shengjuan, L. Zhipeng, F. Xu, and Z. Jinlin, "A new life prediction method of Intelligent meters based on adaptive weighting coefficients," in Journal of Physics: Conference Series, IOP Publishing, 2020, p. 012085.

[27] I. A. Platt, C. Kannangara, M. Tytherleigh, and J. Carson, "The hummingbird project: a positive psychology intervention for secondary school students," Front Psychol, vol. 11, p. 2012, 2020.

[28] J. Bousquet et al., "Operational definition of active and healthy aging (AHA): the European innovation partnership (EIP) on AHA reference site questionnaire: Montpellier October 20–21, 2014, Lisbon July 2, 2015," J Am Med Dir Assoc, vol. 16, no. 12, pp. 1020–1026, 2015.

[29] E. Wouters et al., "The development and piloting of parallel scales measuring external and internal HIV and tuberculosis stigma among healthcare workers in the Free State Province, South Africa," Clinical Infectious Diseases, vol. 62, no. suppl_3, pp. S244–S254, 2016.

# Systematic Review of Rubric Ontology in Higher Education

Noor Maizura Mohamad Noor, Nur Fadila Akma Mamat, Rosmayati Mohemad, Noor Azliza Che Mat
Faculty of Ocean Engineering Technology and Informatics
University Malaysia Terengganu
Kuala Nerus, Terengganu, Malaysia

*Abstract*—Assessing students is a common practice in educational settings. Students will be evaluated using several methods or tools to determine how well they have acquired knowledge or progressed. There are two distinct types of assessment is summative and formative. Rubrics are used to evaluate student performance. However, the development of the rubric is challenging because subject-matter expertise is required. Ontology has been utilized in certain research to communicate knowledge relevant to rubrics, but these studies do not map to the important learning outcomes. Rubrics are developed in Malaysia to support outcome-based education (OBE) based on the Malaysia Qualification Framework (MQF). It is essential to discover if the technology supports rubrics that leverage learning outcomes to produce the best possible rubric. A systematic review of the literature (SLR) was used to carry out this analysis. In the years 2018 through 2022, 42 papers were reviewed. In conclusion, the key finding of this work is that rubric-based outcome learning is the most recent research area to get attention and that only a small number of studies have used ontologies to develop rubrics based on learning outcomes.

*Keywords—Assessment; higher education; learning outcomes; Malaysia Qualification Framework (MQF); ontology; rubric*

## I. INTRODUCTION

The practice of enhancing students' educational experiences by accomplishing learning outcomes through curriculum design is known as outcome-based education (OBE). The OBE process's results are crucial in enabling educational institutions to assess student's performance in an accurate and objective manner and to reassure pertinent stakeholders about the quality and competency of graduates. The OBE process is a crucial tool for promoting the quality of educational institutions, programs, and student employability [1]. OBE is employed in education because it organizes everything in a system of learning around what is essential for all students to be able to do at the end of their studies. [2]. To enhance student performance and learning experiences, OBE must link the curriculum, teaching and learning approaches, and assessment with learning outcomes.

One of the first proponents of OBE, Spady, characterized this approach as the design, production, and documentation of instruction with pre-specified goals and outcomes [3]. The term "outcomes" refers to the learning objectives for any proposed curriculum. These objectives must be clearly defined in order to choose a realistic set of topics and activities that will make up the students' experience [4]. The learning outcomes of the

students are rated according to the Malaysia Qualification Framework (MQF) domain [5].

The curriculum should be developed when a Higher Education Institution (HEI) demonstrates the Program Learning outcome (PLO) that it wants its graduates to achieve. LOs are what the educated can perform because of education. It links with the Course Learning Outcome (CLO). Most courses are expected to foster problem-focused learning skills against the backdrop of academic convergence, improve problem-solving ability, instill criticality, and support creative faculty in the creation of new knowledge. The handling of sophisticated equipment in laboratories and workshops as well as experience with computer-simulated experiments, are expected outcomes of all scientific and technology courses.

The instructional design outlines the process by which students can complete a series of tasks utilizing the resources available in their environment and still meet the learning objectives. Experts claim that objectives oversee connecting general skills to specific knowledge so that learners may prove they can solve specific types of challenges. As a result, various taxonomies pertaining to students' abilities that serve to symbolize the acquisition of information have been constructed. Among them, Bloom's taxonomy is the most widely used [6]. It comprises three important domains: cognitive, affective, and psychomotor. The cognitive domain includes the intellectual area and learning related to knowledge, comprehension, and critical thinking [7]. The affective domain comprises the abilities to communicate and understand feelings, i.e., learning related to senses, emotions, and personal growth in attitudes [8]. The psychomotor domain covers people's abilities to make voluntary movements, skills, and actions [9].

One of the methods to achieve the objectives is through assessment. They need to scale the student's performance. One of the methods is based on assessment, which is done via a platform learning management system (LMS) that store and delivers learning content for training and educating the students. Academic evaluation of students is part of the learning process to monitor their learning progress. The evaluation of the learning process is a thorough and continuous procedure for determining a student's academic performance level in accordance with educational regulations. The assessment will indicate whether the student will succeed or fail, and it will serve as guidance for a teacher in future performance reviews [10].

## A. Assessment

The evaluation criteria, definition criteria, and marking approach are the three key criteria of a rubric, a tool used to evaluate student work [11]. The assessment process requires monitoring of student progress throughout the instructor's planned instruction sequence in the LMS [12]. The objective of the evaluation is to infer, from the students' behavior, what learning objectives were achieved and the level of student knowledge. In this process, the use of a Taxonomy of Educational Objectives is highly recommended [13], [14]. Taxonomy of Educational Objectives can contribute to the evaluation of the student's academic performance.

## B. Rubric

A rubric is a method that educators use to evaluate their students. It is critical to follow the learning objective. Every subject has objectives that need to be archived to qualify the subject and help the educator archive the output from learning. A rubric is used to notify students of expectations, provide informative and timely feedback, help with to grading consistency and fair assessment, and foster student learning and self-assessment [15]. There are two (2) types of rubrics which are analytic and holistic. The analytic rubric breaks down the objective into specific component parts. Every section is scored independently using a rating scale. It is a two-dimensional rubric with levels of achievement as columns and assessment criteria as rows. A holistic rubric consists of a single scale, with all criteria to be included in the evaluation being considered together. It may use a percentage or text-only scoring method.

The performance of the students was evaluated more methodically and objectively, and academics were better informed using standardized rubrics [1]. The educator needs to create teaching and learning activities and assignments that are directly related to the learning outcomes. The knowledge, skills, attitudes, and manners that are the subject of these learning outcomes won't be attained through lectures, tutorial classes, or written tests. The expectations for the performance of students and programs will be better understood with the standardization of a set of rubrics and the appropriate setting of learning outcomes since students will be more inclined to take ownership of their studies [1], [16]–[18]. Rubric is important to teacher/instructor/teaching assistant – Graduate teaching assistants also indicated that they could effectively use the rubrics to assess student work and that the rubrics clarified the instructor's expectations for how they should assess students [19].

In the meantime, the MQF's rubric domain is the evaluation and assessment of students' work using the Integrated Cumulative Grade Point Average (iCGPA) system, which assesses knowledge, skill, and attitude acquired from general subject courses as demonstrated in the Malaysia Qualification Framework's Learning Outcomes Domain (LOD-MQF) [5]. The criteria that educators want to evaluate must point to learning outcomes based on LOD-MQF. Every institution needs to follow Malaysia's Qualification Framework in education to evaluate students. Most of the rubric is created manually with the criteria that want to evaluate [20].

## C. Ontology

Educators can create rubrics easily when using computational approaches. Educators can use ontology to map rubric criteria to related learning outcomes. Ontology is a technology used to represent knowledge domains in an understandable form that can be manipulated by machines. Ontology was created to share a common understanding of the structure of information among people, to enable the reuse of domain knowledge, to make domain assumptions explicit, to separate domain knowledge from operational knowledge, and to analyze the domain knowledge [21]. Developing ontology from scratch is hard and wastes time, however, the study in [22] state that using an existing ontology can save money and effort. The effort of this study, which adapts the pre-established ontology developed by [6], is motivated by the idea of reusing pre-made ontologies.

As employed in this study, a systematic review is an examination of a defined issue that employs methodical and clear techniques to identify, select, and assess pertinent research papers as well as analyze their data [23]. Systematic reviews also try to analyze secondary data by gathering, synthesizing, and rating the available data on a subject in a logical, intelligible, and analytical manner [24]. Given the current discourse issue surrounding this topic, it is imperative to do a thorough study of it. Gaps can be identified and future studies on how educators approach assessment and respond to student learning outcomes can be directed in the right direction using the methodology employed in this analysis.

Based on Systematic Literature Review and meta-analytical analysis, it may show patterns, identify gaps, and offer comparison results [25], [26]. A systematic review aids in understanding pertinent issues that may throw light on various assessments used by educators and enables researchers to identify trends in prior research. It is intended that the learning outcomes of assessments, such as student knowledge, abilities, competencies, and attitudes, will be clearly identified.

## II. Methods

A systematic review needs to do as detail to get accurate result on how the research works. The recommended Preferred Reporting Items for Systematic review and Meta-analysis (PRISMA) guideline technique was used to conduct this systematic literature review. The research in [26], state that identification, screening, and inclusion are the three stages of preparation for papers prepared to utilize the PRISMA approach [27]. Research questions were first developed, and then papers on assessment and the creation of student learning outcomes, competencies, and performances were found. The researchers also talked about data extraction, analysis, and quality evaluation. Many researchers do some research to upgrade or modify the method in teaching and learning. Although, they need to be evaluated to identify the missing knowledge or the part where they are weak. Educator used a rubric to evaluate the student based on formative assessment.

## A. Research Question

Currently, many methods are used to evaluate students using various computational approaches. The research questions for this research are:

- Are there any suitable computerization solutions that could be applied to help educators evaluate the students based on learning outcomes?

- Why ontology for rubric-based assessment is necessary to be used?

### B. Preliminary Research

Preliminary research is used to validate the proposed idea, identify relevant articles, and avoid duplication of the article, and to ensure the article enough to conduct the analysis. This research is about education, and more specifically, is in higher education domain. Therefore, the article that related with the themes will be collected. The issues that appear will be analyzed and considered as important to people.

Search engines such as Google Scholar, Scopus, and Science Direct were used to get the information and documents that related to the research. The key words that used are 'learning', 'teaching', 'problem learning', and 'evaluate student'. The search was too wide, general document was found such as 'SMART learning; and 'Recommender system'. Then the search needs a specific keyword to get a more accurate result on what the research question is about. The specific keywords are 'rubric', 'learning objectives', 'outcome-based education', 'student feedback' and 'taxonomy'. According to the article, there is a gap in the research that has not yet been conducted in the higher education domain.

### C. Inclusion and Exclusion Criteria

To get the desired information and avoid bias from a selection of papers and publications, inclusion and exclusion criteria must be established. Table I lists the article's inclusion and exclusion criteria, the studies in evaluation using the rubric on computational approach. The article was published between 2018 and 2022 and was written in English and was eligible for inclusion in the review. Meanwhile, publications were disqualified if they were studies that are not for evaluation using the rubric, written in a language other than English, did not specifically address the topic of evaluation using rubrics, and were duplicated studies.

TABLE I. INCLUSION AND EXCLUSION CRITERIA

| Inclusion criteria | Exclusion criteria |
|---|---|
| Studies that present OBE, LO, CLO and PLO. | Studies that not for evaluation using rubric |
| Studies in evaluation using rubric | Article that not available in digital library |
| Studies of computation approach in rubric | Non-English written article |
| Studies about conceptual model or theory in Outcome based | Technical reports and documents in the form of summaries |
| Study published between 2018 and 2022 | Studies that related with learning object |
| English written papers | Duplicate studies |

Two levels of inclusion and exclusion criteria were used: first, when reading the title and abstract, and then, after reading the complete article. There are titles, contents, and abstracts for every piece of writing and publication. Some of the book titles don't accurately describe the content. Reading the abstract might therefore save time before reading the entire article by providing an overview of the publication's substance. In addition, it saves us from having to read the full piece to learn what the publication is about and identify its goal or objective. The PRISMA flow diagram template that is used in studies can be found in Fig. 1.
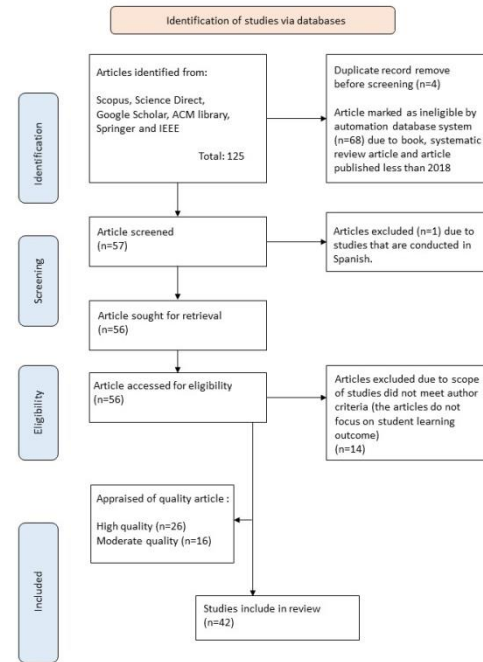


Fig. 1. PRISMA flow diagram.

### D. Search Strategy

The formulation of the research question forms the foundation of the fundamental search strategy. With the assistance of a subject matter expert in the review topic area or an information specialist, search methods are created to include free-text phrases (in the title and abstract) and any applicable subject indexing expected to return acceptable studies. Additionally, because the result is not stated explicitly in the papers, using terms for the outcome may make it more difficult to find qualifying studies in the database because their inclusion. While conducting a trial search and looking for a different pertinent term within each concept from the papers that were collected, the search term is improved.

### E. Search Database, Import and Export Data

According to the A MeaSurement Tool to Assess systematic Reviews (AMSTAR) criteria, the systematic review must search at least two databases [28], but as you increase the number of databases you search, the yield increases and the results become more precise and thorough. The review questions dominate how the databases are arranged. The studies used three databases. While some databases do not permit the usage of Boolean or quotation, others have unique searching methods. To obtain useful results, the original search keywords for each database must change. Lastly, all records are collected into Mendeley library to delete duplicates. All references that have same title and author and published in the same year and also the same title and author and published in the same journal would be deleted.

## F. Title and Abstract Screening

Duplications will be eliminated in this step using Mendeley whenever the reviewers discover them. The team should be inclusive rather than exclusive when there is uncertainty regarding an article decision, at least until the main leader reaches a conclusion after discussion and consensus. There should be an explanation for every excluded record.

## G. Full Text Downloading and Screening

Links to full text articles can be accessed for free using many search engines. If nothing is discovered, the researcher can search on research portals like ResearchGate, Science Direct, which provide the possibility of direct full-text requests from authors.

## H. Manual Search

By explicitly hand-searching for reports that may have been missed in the initial search, one must exhaust all options for reducing bias [29]. The process for manual search; First, reviewing reference lists of articles that were included; second, performing citation tracking, in which reviewers track all the articles that cite each of the articles that were included; this may require using electronic databases; and third, following all "related to" or "similar" articles.

Following the same records produced by electronic databases, every potentially relevant article must be subjected to further examination against the inclusion criteria. To maximize retrieval and reduce bias, the author did an independent evaluation by giving each team member a "tag" and a unique approach before compiling all the data for discussion and comparison of the differences. In a similar vein, the number of included articles must be specified before being added to the total number of included records.

## I. Data Extraction

By gathering data relating to the current issues in education, data extraction was carried out. All the published articles underwent a strengths and weaknesses analysis in this step. Articles are grouped based on the process used to identify rubric-based ontology after the data is extracted. The author's name and, more significantly, the publication year of the piece are listed after that. The article's advantages and disadvantages are combined to assess whether it can help the researcher identify a practical way to know the rubric in the computational approach.

## J. Manuscript Writing, Revision, and Submission to a Journal

Writing that follows a four-part scientific structure which are introduction, methods, results, and discussion, with a conclusion in most cases. A necessary stage that has a template is creating a characteristic table for the study and patient characteristics. When the team has finished writing the manuscript and creating the characteristics table and PRISMA flow diagram, they should send it a leader or thorough revision, respond to his comments, and then choose a suitable journal for the manuscript with a high impact factor and relevant field. Before submitting the work, reading the author's rules of the journals is important.

## III. Result and Discussion

Education is important and required for all people, so they have a wide range of knowledge. Education should be upgraded and use technology to provide many benefits. The majority of researchers have a focus on the university context, mainly in undergraduate research. Some issues in education concern the appropriate learning material [30], such as assessment; students also have issues with their senses, such as visual and auditory [31], and providing feedback [32]. Teachers also have some issues related to their teaching and need to improve learning and teaching methods with Information and Communication Technology (ICTs) [33], [34], and the Internet of Things (IoT) [35]. Students also have a problem choosing the path that they will take. The researcher should take these issues and try to solve the problem by creating a framework for smart learning to personalize learning material, generic smart education design, adaptive learning [36], [37], predict student performance [38], identify learning style [39], and make course recommendations [40] to help students with their studies and choices. Various studies indicate that the learning process may vary depending on the learner [31].

To produce the desired result, the systematic literature review went through each step. The first step was to conduct a thorough search. To search publications and gather data for the research, three Internet databases were employed which is Scopus, Science Direct, ACM library, Springer and IEEE and Google Scholar. There are 78 articles from the identification of the article that are related. Articles, papers, journals, web pages, manuscripts, and books that might be utilized as references for the research were produced from these sources [41]. The main keyword search was 'rubric' followed by the keyword 'evaluation student performance'. The other keyword that was used is already explained in Section B (Preliminary Research). The scope was decreased based on the amount of data retrieved during the search.

Every piece of information, including the research topic, sample type, methodology, evaluation method, participant type, and relevant details, was documented. This will assist the researchers in their data analysis and in determining whether the article is relevant. To gain a different perspective on the publications and to spot the research gaps between the articles, the data was saved as a table. How does it relate, then? It ought to respond to a research question. The author has read that there are four (4) scopes in the field of higher education that have been extensively used and studied. There are numerous perspectives, including (1) instructor perceptions of rubric use, (2) academic achievement in conjunction with rubrics, (3) rubrics for instructional and program assessments, and (4) validity and reliability of rubrics that was support by [42].

In step two (2), all the retrieved articles and publications' inclusion and exclusion criteria were determined. All the articles are then identified and reviewed critically in order to comprehend them. To get precise outcomes from the reading, comprehension is crucial. It is difficult to assess the student's performance on learning objectives using this reading evaluation. As a result, to suggest a remedy to the issue, the research should be in that field.

The data must then be extracted from each and every one of the gathered articles. The article is then extracted and classified using conventional methods, web-based expert systems, ontologies, etc. Based on whether they are PLO or CLO, these four techniques are utilized to determine how learning outcomes are implemented. Articles that discuss the validity and dependability of rubrics, as well as how instructors perceive the usage of them are not included in this article.

In the learning outcome domain research, there are up to 20 articles, as shown in Table II. This study has received considerable consideration from earlier researchers. All the details, including the research topic, sample type, methodology, assessment method, participant type, and relevant information, were documented. This will make it easier for the researchers to assess the data and determine whether the article is relevant. To gain a different perspective on the publications and to spot any gaps in the research among the articles, the data was recorded as a table. How does it relate as a result? A research question should be addressed.

The first analysis is by method that researcher used aim to evaluate, improve, give feedback and verities of solution and method that solve specific problem that related to outcome-based approach. Research used traditional or manual method to conduct exam [43], comparison between different rubric [44], evaluate coursework [20] and performance-based assessment [45], design curriculum [46], [47], improve process skill [19] and creating path [48]. Learning outcome also can be archive by using web based [49]–[53] and expert system such as text mining [54], ontology [6], [55], [56], natural language programming [57] and data mining [58], approach also analytic [59] that need the researcher to develop application. Based on analysis, it shows that only a few researches have been conducted to relate the learning outcome to a rubric evaluation approach using the LOD. The first method that will be employed is a computational technique that makes it simple for educators to assess students based on their learning. Educators can communicate their rubric evaluations using this method of communication virtually. The learning outcome of the student's assessment can also be clearly known, and thus it can be targeted. As a result, the learning objective can be met automatically.

In addition, using the data from the study, the researchers discovered additional ontologies with additional approaches or methodologies for using the expert system to categories individuals according to traits. The topic of the field is the computational method utilizing the scope of research, other than field education; there are two other fields (construction [50] and disaster [52]) that are evaluated based on learning outcomes. It is important to check the quality that greatly benefits others. It gauges how well the initiative succeeds in achieving the desired outcome(s) and how much more justifiable work is needed to attain and/or improve benefits. It offers data that could be utilized to guide decisions in the future. To determine the learning outcomes were focused on is shown in Table III. In the scope of the research, two other fields (building [51] and disaster [52]) are studied based on learning outcomes as well as to field education. It is crucial to look for qualities that are highly advantageous to others. It evaluates the initiative's effectiveness in reaching the desired

outcome(s) and the amount of additional reasonable work required to achieve and/or improve benefits. It provides information that could be used as future decision-making input.

TABLE II. ANALYSIS OF THE LITERATURE REVIEW IN THE OUTCOME BASED APPROACH

| Author and year | Method | Aim |
|---|---|---|
| Parmar et al., 2018 [43] | Traditional/ Manually | To conduct the exam through model making and assessing the graduate students of mechanical engineering |
| Yune et al., 2018 [44] | | To compare holistic rubric and analytic rubric |
| Yaacob & Mahmud, 2019 [20] | | To evaluate subject coursework |
| Dascalu et al., 2019 [46] | | To design curriculum |
| Ram et al., 2020 [47] | | To design curriculum using OBE and LO |
| Gresse Von Wangenheim et al., 2021 [45] | | To evaluate performance-based assessment based on learning outcomes |
| Koutra et al., 2022 [48] | | To creating path and assessment to patient |
| Aji et al., 2018 [49] | Web-based | To develop application in form of mobile apps |
| Demaidi et al., 2018 [50] | | To give personalized feedback |
| Probst et al., 2019 [51] | | To measuring construction safety climate |
| Johnson et al., 2019 [52] | | To design observation rubric |
| Schoch-spana et al., 2019 [53] | | To predicts post-disaster community functioning and resilience |
| Yago et al., 2018 [6] | Expert System | To support student learning |
| Hussain et al., 2018 [58] | | To improve the student performance and to prevent drop out |
| Azmi et al., 2019 [57] | | To automatically evaluate student essay |
| Nouira et al., 2019 [56] | | To support student learning |
| Czajka et al., 2021 [59] | | To give feedback by rubrics |
| Thirumoorthy & Muneeswaran, 2021 [54] | | To identify the best students based on their Course Outcome attainment |
| IMS caliper, 2022 [55] | | To support student learning |

As demonstrated in Table IV, the researcher was also able to locate ontology-based rubrics that link to learning outcomes. A systematic literature review, as opposed to the conventional method, increases the accuracy of the analysis' output and enables more knowledge about the study's topic to be gleaned from the data.

TABLE III.     COMPUTATIONAL APPROACH EVALUATED USING RUBRIC

| Filed | Author and year | Tools/ Project |
|---|---|---|
| Construction | Probst et al., 2019 [51] | Rubric-based Safety Climate Assessment Tool (S-CAT) |
| Disaster | Schoch-spana et al., 2019 [53] | Composite of Post-Event Well-being (COPEWELL) |
| Education | Yago et al., 2018 [6] | Ontology Network-based Student Model for Multiple Learning Environments (ON-SMILLE) |
| | Aji et al., 2018 [49] | e-rubric |
| | Hussain et al., 2018 [58] | WEKA |
| | Azmi et al., 2019 [57] | Automatic evaluation of essay (AAEE) |
| | Nouira et al., 2019 [56] | Experience API (xAPI) |
| | Czajka et al., 2021 [59] | Enhancing Learning by Improving Process Skills in STEM (ELIPSS) analytic rubrics |
| | Thirumoorthy & Muneeswaran, 2021 [54] | Student Recruitment System |
| | IMS caliper [55] | IMS Caliper |
| Special education | Johnson et al., 2019 [52] | Explicit Instruction observation rubric |

TABLE IV.     RUBRIC-BASED ONTOLOGY

| Author and year | Aim |
|---|---|
| Yago et al., 2018 [6] | To do assessments based on rubrics, various sorts of objectives, and learning units should be given to students to determine their knowledge levels. |
| Nouira et al., 2019 [56] | To obtain information from student interactions and disseminate it into different contexts using ontologies and users |
| IMS caliper [55] | To support student learning |

The process of receiving or imparting systematic instruction, especially at a school or university, is referred to as education. Many issues that arise in the education domain that covered by researchers to solve the problem and give appropriate solutions. Education should be upgraded and used technology to provide benefits. MQF is a point of reference to explain and clarify qualifications and academic achievement in higher education with learning outcomes as the target, the MQF includes the eleven Learning Outcome Domains (LODs). This necessitates the curriculum to be designed through the mapping of the course and PLO onto the LODs. A little research has been conducted to relate the learning outcome to a rubric evaluation approach using the LOD-MQF, which can be used as a tool to evaluate students. It is supported by [6] that only used learning objectives in education as course learning outcomes for criteria that were evaluated using rubrics. However, there is no mapping between PLO and CLO. The research in [60] describes another study that focused on the assessment process, evaluation system, and assessment result of the mini project for module Digital System and Microprocessor (ECE511). The project delivered specifications based on existing CLO and aligned with PLO. However, the project does not include a rubric to evaluate student work.

Most researchers just map the course and PLO onto the CLO manually. It is also supported by [20] used the MQF to evaluate the subject coursework. However, the researcher creates a rubric by manually, which can lead to errors in the criteria that must be evaluated. The skill of the educator is lacking, though they follow the MQF to create rubrics. It is because there are some limitations to the impacts of the evaluator's evaluation skills, which encompass several criteria in evaluating proficiency [44]. The educator needs to have knowledge and experience to create a rubric.

According to socioformative methodology by [61], rubric design needs to be reviewed by an expert. The rubric also cannot be shared by other educators in the institution because the knowledge-based which is static. A computational approach using technologies that are ontologies can help the educator define rubric-based learning outcomes, support decision-making using MQF, and make the knowledge easily shareable. It is supported by [62] that state only 12% of researcher applications of ontologies in Higher Education focus on academic evaluation. It is proof that the evaluation of students is vital.

Other ontological approaches to curriculum exist, such as a curriculum ontology for EXTEND centres (international centres that can share data in a network of centers), knowledge transfer between centres in different countries and regions, exchange activities between those centres, double graduation certificates, and so on [46]. However, this curriculum was not implemented in Malaysia and was only exploited in Russia and Tajikistan. Another development is a website that used IMS Caliper model that apply ontological approach for framework. It also creates 16 rubrics based on learning outcomes [55]. The model also focuses on learning analytics [63]. The IMS Caliper framework is described in a way that is not entirely apparent, but it comprises of an ontology model that is applied to the rubric notion without having a learning outcome. Additionally, this rubric is not applicable in Malaysia because Malaysia has its own OBE framework.

According to the [56], xAPI specifications enable learning environments to capture data from student interactions and to share it with other environments using ontologies and users, but this model of xAPI does not have evaluation of students by assessment that is used rubric based learning outcome. The research by [64] shows that the researcher used an ontology approach in the engineering education field using the MQF. It is proposed that an ontology present a common vocabulary that facilitates electrical engineering curriculum development. The researcher, however, did not concentrate on evaluating students using a rubric-based map with learning outcomes. Fig. 2 show a part of ontological xAPI data model.

Research by [6], ON-SMMILE aims to promote student learning by developing a theoretical framework that makes use of the AR (Assessment Rubric) ontology model of rubric ontology. This ontology was modified from the rubric ontology [65]. The model of the rubric ontology is depicted in Fig. 3. The approach still doesn't apply to learning outcome based. An overview of the ON-SMMILE model is presented in Fig. 4.

This literature review demonstrates a few studies on an ontology design for PLO linked with CLO in higher education domain, particularly in support of the outcome-based learning and design rubric. With ontology, researchers or experts that conduct studies in the field of higher education can exchange and reuse the knowledge included in the model. It can also expressly state any domain assumptions. It is simple to alter the domain knowledge if it changes.
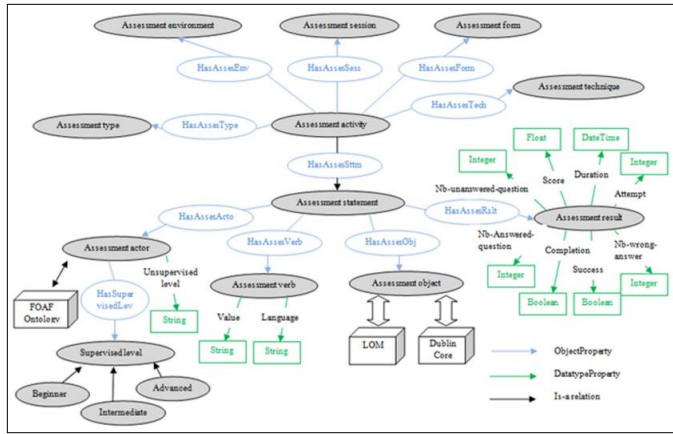


Fig. 2. A part of ontological xAPI data model [56].
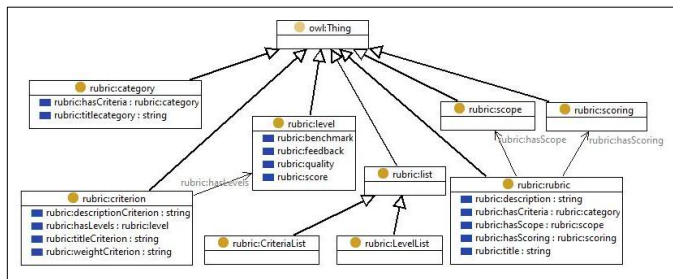


Fig. 3. Rubric based ontology [65].

In comparison to the standard method of conducting a literature review, a systematic literature review improves the accuracy of the analysis's output and makes it possible to glean more information about the subject of study from the data. It aids in the development of a structured literature review. The final step is to write a technical report or article about the complete systematic literature review process.

A structured literature review is beneficial. The final step is to write a technical report or article about the complete step in the systematic literature review process. Based on researchers' findings in the existing literature, none of the researchers used a rubric-based ontology to map CLO and align them with PLO. This rubric helps the educator create a rubric based on learning outcomes guided by the MQF.

## IV. CONCLUSION

A systematic approach to the literature review is necessary to produce accurate results from relevant studies. To stay current with the research and to include new discoveries by other researchers, a literature review may need to be updated frequently. The steps in a systematic review or meta-analysis include developing a research question and validating it,

creating criteria, searching databases, importing all results into a library, and exporting them to an Excel sheet. They also include writing a protocol and registering it; screening titles, abstracts, and full texts manually; extracting data and evaluating its quality; conducting statistical analysis manually; double-checking the data; writing a manuscript and revising it.
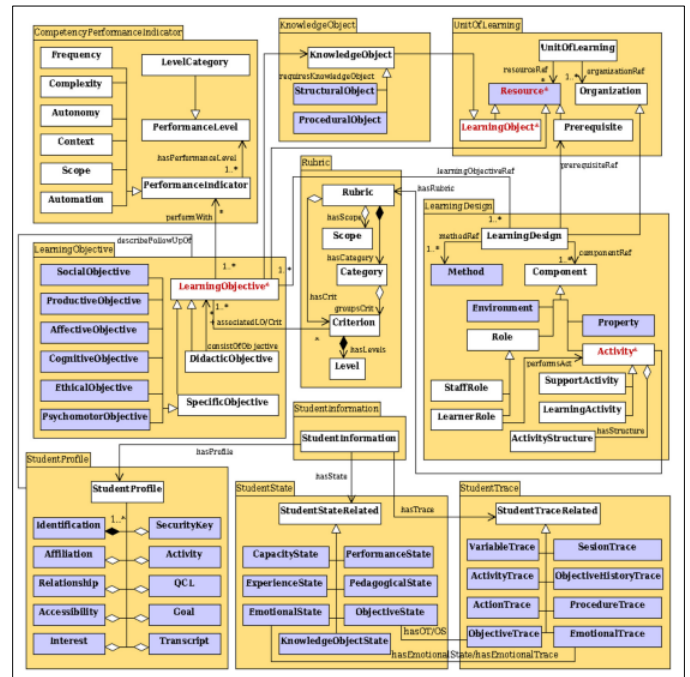


Fig. 4. The overview of the model of ON-SMMILE [6].

In this comprehensive research analysis, the characteristics of the most recent studies about the development of rubrics for student evaluation have been outlined and synthesized. The following is a summary of the key results from the literature review and the studied that were examined:

RQ1: Computational methods are now more frequently used in higher education to make complex problems simpler. However, there is still a need for a thorough analysis that provides an overview of how and to what extent computational approaches are integrated and implemented to address different concerns in higher education. To create a rubric based on learning outcomes, none of the scholars have employed the ontology technique or model. This aids in developing an appropriate framework for creating rubrics that are based on PLO and CLO.

RQ2: Ontology for rubric-based assessment is necessary to be used in PLO links with CLO because it is easy for educators to design rubric-based outcome-based learning that is guided by the MQF. Aside from that, the rubric ontology can be shared by other Malaysian educational institutions.

With these findings, researchers believe that scholars will better understand how the stages of computational techniques are employed when constructing a rubric, particularly for evaluating students, due to this thorough literature study. Researchers propose a study that focuses on the design of rubric-based outcome learning as future work to find solutions to fill gaps in this systematic literature review, such as the

interoperability issue and the understudied area of software needs. Focusing on the technology and approach techniques utilized in the development of a rubric utilizing outcome-based learning is another possibility.

## ACKNOWLEDGMENT

## REFERENCES

[1] P. H. Sun and S. Y. Lee, "The importance and challenges of outcomebased education - A case study in a private higher education institution," Malaysian J. Learn. Instr., vol. 17, no. 2, pp. 253–278, 2020, doi: 10.32890/mjli2020.17.2.9.

[2] H. M. Asim, A. Vaz, A. Ahmed, and S. Sadiq, "A Review on Outcome Based Education and Factors That Impact Student Learning Outcomes in Tertiary Education System," Int. Educ. Stud., vol. 14, no. 2, p. 1, 2021, doi: 10.5539/ies.v14n2p1.

[3] L. Saiyachit, "Effectiveness of outcome-based approach to design contents for training secondary school English teachers in Laos," J. Green Learn., vol. 2, no. 1, pp. 10–15, 2022, doi: 10.53889/jgl.v2i1.99.

[4] L. N. Cassel et al., "The Computing Ontology -Application in Education General Terms," ACM SIGCSE Bulletin, vol. 39, pp. 171–183, 2007.

[5] Ministry of Higher Education Putrajaya Malaysia, iCGPA Rubric Learning Outcomes Assessment Guide. 2016.

[6] H. Yago, J. Clemente, D. Rodriguez, and P. Fernandez-de-Cordoba, "ON-SMMILE: Ontology Network-based Student Model for Multiple Learning Environments," Data Knowl. Eng., vol. 115, no. June 2017, pp. 48–67, 2018, doi: 10.1016/j.datak.2018.02.002.

[7] M. E. Hoque, "Three Domains of Learning: Cognitive , Affective and Psychomotor," J. EFL Educ. Res., vol. 2, no. September 2016, pp. 45–52, 2016.

[8] J. S. Nelson, D. A. Pender, C. E. Myers, and D. Sheperis, "The Effect of Affect : Krathwohl and Bloom ' s Affective Domains Underutilized in Counselor Education," J. Couns. Prep. Superv., vol. 13, no. 1, 2020.

[9] A. Casas-Ortiz, J. Echeverria, and O. C. Santos, "Intelligent systems for psychomotor learning: A systematic review and two case of study," in Handbook of Artificial Intelligence in Education, 2023, pp. 390–420.

[10] E. Budiman, Haviluddin, N. Dengan, A. H. Kridalaksana, M. Wati, and Purnawansyah, "Performance of Decision Tree C4.5 Algorithm in Student Academic Evaluation," Lect. Notes Electr. Eng., vol. 488, no. April, pp. 380–389, 2018, doi: 10.1007/978-981-10-8276-4_36.

[11] P. Dawson, "Assessment rubrics: towards clearer and more replicable design, research and practice," Assess. Eval. High. Educ., vol. 42, no. 3, pp. 347–360, 2017, doi: 10.1080/02602938.2015.1111294.

[12] M. Sampieri Bulbarela, "Monitoring the learning progress. Monitorización del progreso en el aprendizaje," 2008.

[13] B. S. Bloom, M. D. Engelhart, E. J. Furst, W. H. Hill, and D. R. Krathwohl, Taxonomy of Educational Objectives: The Classification of Educational Goals. Handbook 1 Cognitive Domain. United States of America: Domain of Canada, 1956. doi: 10.1300/J104v03n01_03.

[14] L. A. Costa, L. N. Salvador, and R. R. Amorim, "Evaluation of Academic Performance Based on Learning Analytics and Ontology: A Systematic Mapping Study," in Proceedings - Frontiers in Education Conference, FIE, 2019, vol. 2018-Octob. doi: 10.1109/FIE.2018.8658936.

[15] F. Chowdhury, "Application of Rubrics in the Classroom: A Vital Tool for Improvement in Assessment, Feedback and Learning," Int. Educ. Stud., vol. 12, no. 1, p. 61, 2018, doi: 10.5539/ies.v12n1p61.

[16] N. Gunarathne, "Outcome-based education in accounting The case of an accountancy degree," 2019, doi: 10.1108/JEAS-08-2018-0093.

[17] K. E. Matthews and L. D. Mercer-mapstone, "Studies in Higher Education Toward curriculum convergence for graduate learning outcomes : academic intentions and student experiences," Stud. High.

[18] Educ., vol. 0, no. 0, pp. 1–16, 2017, doi: 10.1080/03075079.2016.1190704.

[18] A. Z. Reich, G. R. Collins, A. L. DeFranco, and S. L. Pieper, "A recommended closed-loop assessment of learning outcomes process for hospitality programs," Int. Hosp. Rev., vol. 33, no. 1, pp. 41–52, 2019, doi: 10.1108/ihr-09-2018-0010.

[19] G. Reynders, J. Lantz, S. M. Ruder, C. L. Stanford, and R. S. Cole, "Rubrics to assess critical thinking and information processing in undergraduate STEM courses," Int. J. STEM Educ., vol. 7, no. 1, 2020, doi: 10.1186/s40594-020-00208-5.

[20] Y. Yaacob and M. M. Mahmud, "Evaluating the Islamic Studies Subject's Coursework Within the Paradigm of the Malaysian Qualifications Framework (MQF) Rubric," in 2nd International Conference on Educational Assessment and Policy (ICEAP 2019), 2019, no. December, pp. 186–194. doi: 10.26499/iceap.v0i0.220.

[21] N. F. Noy and M. Musen, "PROMPT: Algorithm and Tool for Automated Ontology Merging and Alignment," in 17th National Conference on Artificial Intelligence (AAAI'00), 2000, pp. 450–455.

[22] M. Ra, D. Yoo, S. No, J. Shin, and C. Han, "The mixed ontology building methodology using database information," Lect. Notes Eng. Comput. Sci., vol. 2195, pp. 68–73, 2012.

[23] J. P. T. Higgins, D. G. Altman, P. C. Gøtzsche, P. Jüni, D. Moher, and A. D. Oxman, "The Cochrane Collaboration ' s tool for assessing risk of bias in randomised trials," pp. 1–9, 2011, doi: 10.1136/bmj.d5928.

[24] F. Martin, V. P. Dennen, C. J. Bonk, and F. Martin, "A synthesis of systematic review research on emerging learning environments and technologies," Educ. Technol. Res. Dev., vol. 68, no. 4, pp. 1613–1633, 2020, doi: 10.1007/s11423-020-09812-2.

[25] I. Fernández, J. Ahmet, R. Roy, R. Palmarini, and D. Onoufriou, "Computers in Industry A systematic review of Augmented Reality content-related techniques for knowledge transfer in maintenance applications," Comput. Ind., vol. 103, pp. 47–71, 2018, doi: 10.1016/j.compind.2018.08.007.

[26] W. Mengist, T. Soromessa, and G. Legese, "Method for conducting systematic literature review and meta-analysis for environmental science research," MethodsX, vol. 7, p. 100777, 2020, doi: 10.1016/j.mex.2019.100777.

[27] H. Azril, M. Shaffril, A. A. Samah, and S. F. Samsuddin, "Guidelines for developing a systematic literature review for studies related to climate change adaptation," Environ. Sci. Pollut. Res., pp. 22265–22277, 2021.

[28] B. J. Shea et al., "AMSTAR 2 : a critical appraisal tool for systematic reviews that include randomised or non-randomised studies of healthcare interventions , or both," BMJ 2017;358j4008, pp. 1–9, 2017, doi: 10.1136/bmj.j4008.

[29] M. Vassar, P. Atakpo, and M. J. Kash, "Manual search approaches used by systematic reviewers in dermatology," Res. Commun., vol. 104, pp. 2015–2017, 2016, doi: http://dx.doi.org/10.3163/1536-5050.104.4.009.

[30] R. K. Sungkur and M. S. Maharaj, "Design and implementation of a SMART Learning environment for the Upskilling of Cybersecurity professionals in Mauritius," Educ. Inf. Technol., pp. 3175–3201, 2021.

[31] S. El Janati, A. Maach, and D. El Ghanami, "SMART education framework for adaptation content presentation," Procedia Comput. Sci., vol. 127, pp. 436–443, 2018, doi: 10.1016/j.procs.2018.01.141.

[32] Y. Kim, T. Soyata, and R. F. Behnagh, "Towards Emotionally Aware AI Smart Classroom: Current Issues and Directions for Engineering and Education," IEEE Access, vol. 6, pp. 5308–5331, 2018, doi: 10.1109/ACCESS.2018.2791861.

[33] K. A. Demir, "Smart education framework," Smart Learn. Environ., vol. 8, no. 1, 2021, doi: 10.1186/s40561-021-00170-x.

[34] S. Hartono, R. Kosala, S. H. Supangkat, and B. Ranti, "Smart Hybrid Learning Framework Based on Three-Layer Architecture to Bolster Up Education 4.0," Proceeding - 2018 Int. Conf. ICT Smart Soc. Innov. Towar. Smart Soc. Soc. 5.0, ICISS 2018, no. 2017, pp. 1–5, 2018, doi: 10.1109/ICTSS.2018.8550028.

[35] K. Palanivel, "Smart Education Architecture Using the Internet of Things (Iot) Technology," Int. J. Manag. IT Eng., vol. 9, no. 4, pp. 1–27, 2019.

[36] M. R. Asad, N. Tadvi, K. M. Amir, K. Afzal, A. Irfan, and S. A. Hussain, "Medical Student's Feedback towards Problem Based Learning and Interactive Lectures as a Teaching and Learning Method in an Outcome-Based Curriculum," Int. J. Med. Res. Heal. Sci., vol. 8, no. 4, pp. 78–84, 2019.

[37] N. Morze, L. Varchenko-Trotsenko, T. Terletska, and E. Smyrnova-Trybulska, "Implementation of adaptive learning at higher education institutions by means of Moodle LMS," J. Phys. Conf. Ser., vol. 1840, no. 1, 2021, doi: 10.1088/1742-6596/1840/1/012062.

[38] J. López-Zambrano, J. A. Lara, and C. Romero, "Improving the portability of predicting students' performance models by using ontologies," J. Comput. High. Educ., no. 15, 2021, doi: 10.1007/s12528-021-09273-3.

[39] R. Bajaj and V. Sharma, "Smart Education with artificial intelligence based determination of learning styles," Procedia Comput. Sci., vol. 132, pp. 834–842, 2018, doi: 10.1016/j.procs.2018.05.095.

[40] M. E. Ibrahim, Y. Yang, D. L. Ndzi, G. Yang, and M. Al-Maliki, "Ontology-Based Personalized Course Recommendation Framework," IEEE Access, vol. 7, pp. 5180–5199, 2019, doi: 10.1109/ACCESS.2018.2889635.

[41] C. Cooper, A. Booth, J. Varley-campbell, N. Britten, and R. Garside, "Defining the process to literature searching in systematic reviews : a literature review of guidance and supporting studies," BMC Med. Res. Methodol., pp. 1–14, 2018, doi: https://doi.org/10.1186/s12874-018-0545-3.

[42] E. Park, A. Leonard, J. S. Delano, X. Tang, and D. M. Grzybowski, "Rubric-based assessment of entrepreneurial minded learning in engineering education: A review," Int. J. Eng. Educ., vol. 36, no. 6, pp. 2015–2029, 2020.

[43] H. L. Parmar, P. Muralinath, and J. M. Parmar, "Rubric Based Assessment of Model Making : An Outcome based Approach," J. Eng. Educ. Transform., pp. 2–6, 2018.

[44] S. J. Yune, S. Y. Lee, S. J. Im, B. S. Kam, and S. Y. Baek, "Holistic rubric vs. analytic rubric for measuring clinical performance levels in medical students," BMC Med. Educ., vol. 18, no. 1, pp. 1–6, 2018, doi: 10.1186/s12909-018-1228-9.

[45] C. Gresse Von Wangenheim, N. da C. Alves, M. F. Rauber, J. C. R. Hauck, and I. H. Yeter, "A Proposal for Performance-based Assessment of the Learning of Machine Learning Concepts and Practices in K-12," Informatics Educ., vol. 21, no. 3, pp. 479–500, 2021, doi: 10.15388/infedu.2022.18.

[46] M.-I. Dascălu, E. Lazarou, M. Nițu, I. Stanică, C.-N. Bodea, and A.-M. Dobrescu, "Ontologies - Facilitators for Curriculum Design in Centers of Excellence for Engineering Education," in The 15th International Scientific Conference eLearning and Software for Education, 2019, no. May 2019, pp. 11–18. doi: 10.12753/2066-026X19-138.

[47] M. P. Ram, K. K. Ajay, and A. Gopinathan Nair, "Geoscience Curriculum: Approach Through Learning Taxonomy and Outcome Based Education," High. Educ. Futur., vol. 7, no. 1, pp. 22–44, 2020, doi: 10.1177/2347631119886403.

[48] K. Koutra, C. Burns, L. Sinko, S. Kita, H. Bilgin, and D. Saint Arnault, "Trauma Recovery Rubric: A Mixed-Method Analysis of Trauma Recovery Pathways in Four Countries," Int. J. Environ. Res. Public Health, vol. 19, no. 16, 2022, doi: 10.3390/ijerph191610310.

[49] S. D. Aji, M. N. Hudha, C. Huda, A. B. D. Nandiyanto, and A. G. Abdullah, "The improvement of learning effectiveness in the lesson study by using e-rubric," J. Eng. Sci. Technol., vol. 13, no. 5, pp. 1181–1189, 2018.

[50] M. N. Demaidi, M. M. Gaber, and N. Filer, "OntoPeFeGe: Ontology-based personalized feedback generator," IEEE Access, vol. 6, pp. 31644–31664, 2018, doi: 10.1109/ACCESS.2018.2846398.

[51] T. M. Probst, L. M. Goldenhar, J. L. Byrd, and E. Betit, "The Safety Climate Assessment Tool (S-CAT): A rubric-based approach to measuring construction safety climate," J. Safety Res., vol. 69, pp. 43–51, 2019, doi: 10.1016/j.jsr.2019.02.004.

[52] E. S. Johnson, Y. Zheng, A. R. Crawford, and L. A. Moylan, "Developing an Explicit Instruction Special Education Teacher Observation Rubric," J. Spec. Educ., vol. 53, no. 1, pp. 28–40, 2019, doi: 10.1177/0022466918796224.

[53] M. Schoch-spana et al., "The COPEWELL Rubric : A Self-Assessment Toolkit to Strengthen Community Resilience to Disasters," Int. J. Environ. Res. Public Health, vol. 16, no. 13, pp. 1–17, 2019, doi: https://doi.org/10.3390/ijerph16132372.

[54] K. Thirumoorthy and K. Muneeswaran, "An application of text mining techniques and outcome based education: student recruitment system," J. Ambient Intell. Humaniz. Comput., p. 13, 2021, doi: 10.1007/s12652-021-03162-4.

[55] I. 1EdTechTM Consortium, "Caliper Analytics®," 2022. https://www.imsglobal.org/activity/caliper

[56] A. Nouira, L. Cheniti-Belcadhi, and R. Braham, "An ontology-based framework of assessment analytics for massive learning," Comput. Appl. Eng. Educ., vol. 27, no. 6, pp. 1343–1360, 2019, doi: 10.1002/cae.22155.

[57] A. M. Azmi, M. F. Al-Jouie, and M. Hussain, "AAEE – Automated evaluation of students' essays in Arabic language," Inf. Process. Manag., vol. 56, no. 5, pp. 1736–1752, 2019, doi: 10.1016/j.ipm.2019.05.008.

[58] S. Hussain, N. A. Dahan, F. M. Ba-Alwib, and N. Ribata, "Educational data mining and analysis of students' academic performance using WEKA," Indones. J. Electr. Eng. Comput. Sci., vol. 9, no. 2, pp. 447–459, 2018, doi: 10.11591/ijeecs.v9.i2.pp447-459.

[59] D. Czajka, G. Reynders, C. Stanford, R. S. Cole, J. Lantz, and S. Ruder, "A Novel Rubric Format for Providing Feedback on Process Skills to STEM Undergraduate Student," J. Coll. Sci. Teach., vol. 50, no. 6, pp. 48–56, 2021.

[60] W. Mansor et al., "Preliminary Results on The Implementation of Outcome-Based Education on The Non-Examinable Computer Engineering Modules," in 2008 38th Annual Frontiers in Education Conference, 2008, pp. 20–25.

[61] M. L. S. Contreras, "Socioformative Taxonomy: A referent for Didactics and Evaluation. [Taxonomía Socioformativa: Un Referente para la Didáctica y la Evaluación].," Forhum Int. J. Soc. Sci. Humanit., vol. 1, no. 1, pp. 100–115, 2019, doi: https://doi.org/10.35766/jf19119.

[62] M. T. Leon, J. Chicaiza, and S. L. Mora, "Application of ontologies in higher education: A systematic mapping study," in 2018 IEEE Global Engineering Education Conference (EDUCON), 2018, 2018, pp. 1344–1353. doi: 10.1109/EDUCON.2018.8363385.

[63] L. A. Costa et al., "Monitoring Academic Performance Based on Learning Analytics and Ontology : A Systematic Review," vol. 19, no. 3, pp. 361–397, 2020, doi: 10.15388/infedu.2020.17.

[64] A. Tang, "An ontological approach to curriculum development," 2009 Int. Conf. Eng. Educ. ICEED2009 - Embrac. New Challenges Eng. Educ., no. lCEED, pp. 219–224, 2009, doi: 10.1109/ICEED.2009.5490580.

[65] B. Panulla and M. Kohler, "An Ontology for Open Rubric Exchange on the Web," 2010. [Online]. Available: http://hdl.handle.net/10609/5222

# A Prediction of South African Public Twitter Opinion using a Hybrid Sentiment Analysis Approach

Matthew Brett Shackleford[1], Timothy Temitope Adeliyi[2], Seena Joseph[3]*

Department of Information Technology, Durban University of Technology, Durban, South Africa[1, 3]

Engineering, Built Environment, and Information Technology, University of Pretoria, Pretoria, South Africa[2]

*Abstract*—Sentiment analysis, a subfield of Natural Language Processing, has garnered a great deal of attention within the research community. To date, numerous sentiment analysis approaches have been adopted and developed by researchers to suit a variety of application scenarios. This consistent adaptation has allowed for the optimal extraction of the authors emotional intent within text. A contributing factor to the growth in application scenarios is the mass adoption of social media platforms and the bondless topics of discussion they hold. For government, organizations and other miscellaneous parties, these opinions hold vital insight into public mindset, welfare, and intent. Successful utilization of these insights could lead to better methods of addressing said public, and in turn, could improve the overall state of public well-being. In this study, a framework using a hybrid sentiment analysis approach was developed. Various amalgamations were created – consisting of a simplified version of the Valence Aware Dictionary and sEntiment Reasoner (VADER) lexicon and multiple instances of classical machine learning algorithms. In this study, a total of 67,585 public opinion-oriented Tweets created in 2020 applicable to the South African (ZA) domain were analyzed. The developed hybrid sentiment analysis approaches were compared against one another using well known performance metrics. The results concluded that the hybrid approach of the simplified VADER lexicon and the Medium Gaussian Support Vector Machine (MGSVM) algorithm outperformed the other seven hybrid algorithms. The Twitter dataset utilized serves to demonstrate model capability, specifically within the ZA context.

*Keywords*—*Sentiment analysis; opinion mining; machine learning; government; public service delivery; twitter*

## I. INTRODUCTION

Communication has become more dynamic due to the widespread adoption of both mobile devices and the Internet; this has allowed for people to express themselves regardless of location. In both the public and private sectors, organizations have either begun or currently leverage technical methods of analyzing public opinion [1-4]. Governments and organizations deemed the assessment necessary to gain a full understanding of the emotional state of a specific group in relation to that of their own performance [5].

Sentiment analysis or alternatively referred to as opinion mining, is a branch of Natural Language Processing that uses a variety of methods to determine an author's positive, negative, and neutral emotional stance from snippets of their writing [6]. Typically, analysis takes place at an aspect, sentence, or document level, however a combination of levels is an additional possibility and at times - can offer a more comprehensive perspective. Successful sentiment analysis would be the precise extraction of the emotions surrounding a viewpoint within the context in which correct interpretation was intended by the author [7].

A significant proportion of the sentiment analysis attempts in the South African (ZA) context have been geared toward specific events or themes, such as gauging perspectives on ethnic division [8], sexual violence [9], and the #FeesMustFall campaign [10]. This focus on judging instances ignores the importance of attaining a multidisciplinary model qualified to assess the emotional state of the ZA population, throughout a multitude of varying scenarios.

Sims determined in [11] that losing track of the public's opinion or neglecting a society's overall emotional state can lead to unfavorable public behavior, such as protests, which has a multifaceted and detrimental influence on the country. One can conclude that an accurate means of analyzing the Tweets of ZA public perception, would result in the emotional state of the public being handled in a more proactive and effective manner. Furthermore, such a model might be used to detect future communication patterns that may fluctuate the emotional state of the targeted demographic (positively or negatively). As more people around the world utilize social media to communicate their thoughts and feelings, the necessity to iteratively construct a better system of assessing an author's sentiment, using various sentiment analysis approaches that are suitable for the intended provided circumstances, becomes a challenge [12].

This study serves as an example that the created model may additionally work within the context of other countries, as the Valence Aware Dictionary and sEntiment Reasoner (VADER) lexicon is not specific to the ZA domain in which it succeeded - but rather likely the American domain from whence it came. The testing and creation of a novel sentiment analysis hybrid geared toward social media is highly beneficial, as it serves globally as an option for social media text analysis. Additionally, it was created with the hopes of effectively analyzing social media within the ZA context. As mentioned later in the related works section, hybrids have the tendency of outperforming standalone lexicon and machine learning models. As suggested, a social media hybrid model such as the hybrid in this study might be better suited to reanalyze the #FeesMustFall dataset [10].

The layout hereafter is as follows. A brief overview of the literature in Section II. Section III focuses on: the VADER and Twitter dataset; hardware and software used; study

architecture; planned approach; data preparation and processing; machine learning model parameters; evaluation criteria; as well as Twitter dataset preparation, processing, and evaluation. Section IV focuses on an analysis of the results. Section V consists of speculation over the results. Limitations of the study are highlighted in Section VI. The concluding remarks are found in Section VII. Future research is briefly discussed in Section VII.

## II. Related Work

There are four supervised classification algorithm types that contain models commonly used for sentiment analysis, according to Birjali et al., [13]. The first is a Linear approach, a statistical method for categorizing sentiment using hyperplane or linear decision boundaries. The linear approach ultimately outputs the most probable class (either negative or positive within the sentiment analysis domain) of a prescribed input. Secondly and in contrast to the linear technique, the probabilistic classifier – typically founded on Bayes' theorem – works by predicting a probability distribution over a set of classes. The third approach is rule-based classification, which refers to any classification scheme that uses IF-THEN rules to predict class membership. As a result, a set of rules ultimately guides the classifier in this technique to accomplish sentiment classification. The fourth option is the decision tree strategy, which decomposes the training data space hierarchically using an attribute value condition to classify input data into a limited quantity of predetermined classes. Additionally, the ensemble approach exists as a varied combination of the above approaches. The fundamental proposition behind this idea is to form an ensemble of different classifiers that outperform their standalone examples.

The authors in [14,15] attempted to apply and compare a variety of machine learning models, however, their results varied depending on the methodologies and datasets employed. This is mainly because a machine learning model that performs well in one trial does not necessarily guarantee equivalent performance in subsequent studies, due to varying circumstance. As results differ, models need to be tested separately under exact circumstances. Traditional machine learning approaches use a single learner method; however, an ensemble approach uses numerous learner methods to better leverage each learner's unique strengths while also covering any shortcomings that may exist, resulting in increased model precision and reliability [16,17]. When opposed to using a single classifier model, the most significant disadvantage of ensemble techniques is the additional processing time and power required [13].

Bagging, boosting, stacking and voting are the ensemble approaches leveraged to better the results of traditional standalone machine learning models [15, 18]. Bagging is a bootstrap aggregating prediction ensemble machine learning technique. Boosting ensemble is a strategy for training a set of weak classifiers that were previously poorly trained [19]. When presented with noisy data, such as unstructured Twitter text, boosting is more sensitive, while bagging is more resistant [20]. Despite this, boosting strategies have been utilized in several studies to increase model performance [21, 22]. Stacking is an ensemble model where various diverse methods

are devised using training data [18]. The use of the ensemble machine learning method to analyze sentiment is limited [23]. This additionally holds true with the analysis of ZA citizen text via digital platforms.

An ensemble machine learning strategy that focuses solely on learning classifier combinations is successful in multiple investigations [15, 24]. To obtain a final prediction, the voting ensemble approach uses pre-processing sentiment analysis, feeding several algorithms, and then integrating the results into a voting average method. Other models may use various components at different stages while still adhering to the same process. An ensemble method in the literature performed well throughout the evaluation when different classical machine learning algorithms were placed via a vote on average probability approach.

Pre-trained word embeddings are created using Bidirectional Encoder Representations from Transformers (BERT), an ensemble of binary classifiers [25]. The feature selection and feature extraction processes used in sentiment analysis pre-processing are not required because this approach takes tokenization as input [26]. As a result, researchers in [25] observed that a combination of BERT supplied pre-trained word embeddings along with the Random Forest classifier led to an accuracy of 94%, exceeding current models at the time of publication. The study in [26] achieved comparable success when creating a BERT - Support Vector Machine hybrid model, attaining 94% accuracy.

Hybrid sentiment analysis models typically exist as a combination of machine learning and lexical approaches. Hybrid sentiment analysis models are popular as an alternative for sentiment analysis as they combine the versatility of machine learning algorithms with the superior performance of lexicons [27, 28]. When compared to the state-of-the-art machine learning and lexicon approaches available, Abd El-Jawad et al [14] discovered that hybrid models tended to outperform the latter. As a result, it is concluded that hybrid sentiment analysis approaches would seem to offer top results.

One of the more widely used supervised machine learning techniques within the sentiment analysis domain is the Support Vector Machine (SVM) algorithm [29]. While the original SVM model uses a linear hyperplane, non-linear hyperplane models are often accommodated using a kernel method such as the Gaussian function. The Medium Gaussian Support Vector Machine (MGSVM) deals well with data of medium complexity and adopt the kernel scale $\sqrt{P}$ – where the value $P$ refers to the dimension size or the number of features of the vector $x_i$ [30, 31].

Many lexical approaches exist such as the manual, dictionary-based, corpus-based, and statistical approaches to name a few, and within these approaches lay a variety of lexicons [13]. One lexical approach that has proven to be a valuable outlier within the social media sentiment analysis domain is the VADER lexicon. The VADER lexicon is tuned towards assessing contents like that of a microblog and has particularly succeeded in the social media domain [32].

Based on the advantages of both the MGSVM and VADER approaches as well as the hybrid approaches tendency to

outperform standalone models, a gap in the literature was found where a hybrid of the two was yet to be created. This study sought to create a hybrid of the two as well as various other hybrid approaches, to compare and establish an effective means of assessing ZA public Twitter opinion.

## III. MATERIALS AND METHOD

The VADER lexicon contains a lexical corpus that holds a variety of words and their associated negative or positive numerical weighting depending on the keyword's perception and has been empirically validated by various individuals [32]. The VADER lexical dataset was obtained and is freely accessible via GitHub [32]. Based on the keyword sentiment weighting, the July 2019 version of the VADER lexical dataset contains 7517 keywords, 3344 of which are classed as positive and 4173 as negative. The hybrid model was also evaluated on a dataset of ZA public Tweets from the public repository site Kaggle. The experiment was performed using MATLAB R2021b on a Windows 10 Professional machine.

The study architecture is depicted in Fig. 1. The hybrid model creation and selection process takes place in the first stage, whereas the capability of the chosen hybrid model is tested on a ZA public dataset in the second stage. In this study,

a hybrid strategy with two stages is developed to overcome the shortcomings of the separate techniques.

### A. Stage 1 – Creating a Top-Performing Hybrid Model:

Five-fold cross-validation was used to train each model. The use of this validation method minimizes the effects of sampling bias. This is done through the random division of the lexical dataset – into five equal sections. Four of the five equal sections are used to train the algorithm, with the remaining section set aside to test the algorithm. This is repeatedly done until all combinations of the test/training set have been exhausted and, the resultant model produced is the mean of the training iterations [33]. Additionally, this procedure was opted for as it prevents both overfitting and underfitting to provide a more exact result.

Simplified VADER lexicon – The original VADER lexicon is acquired, and the keywords are assigned polarity, either positive or negative depending on their allocated numerical rating. The simplified VADER dataset is utilized to train various classical machine learning models. These hybridized models are evaluated utilizing performance evaluation measures at a later stage.
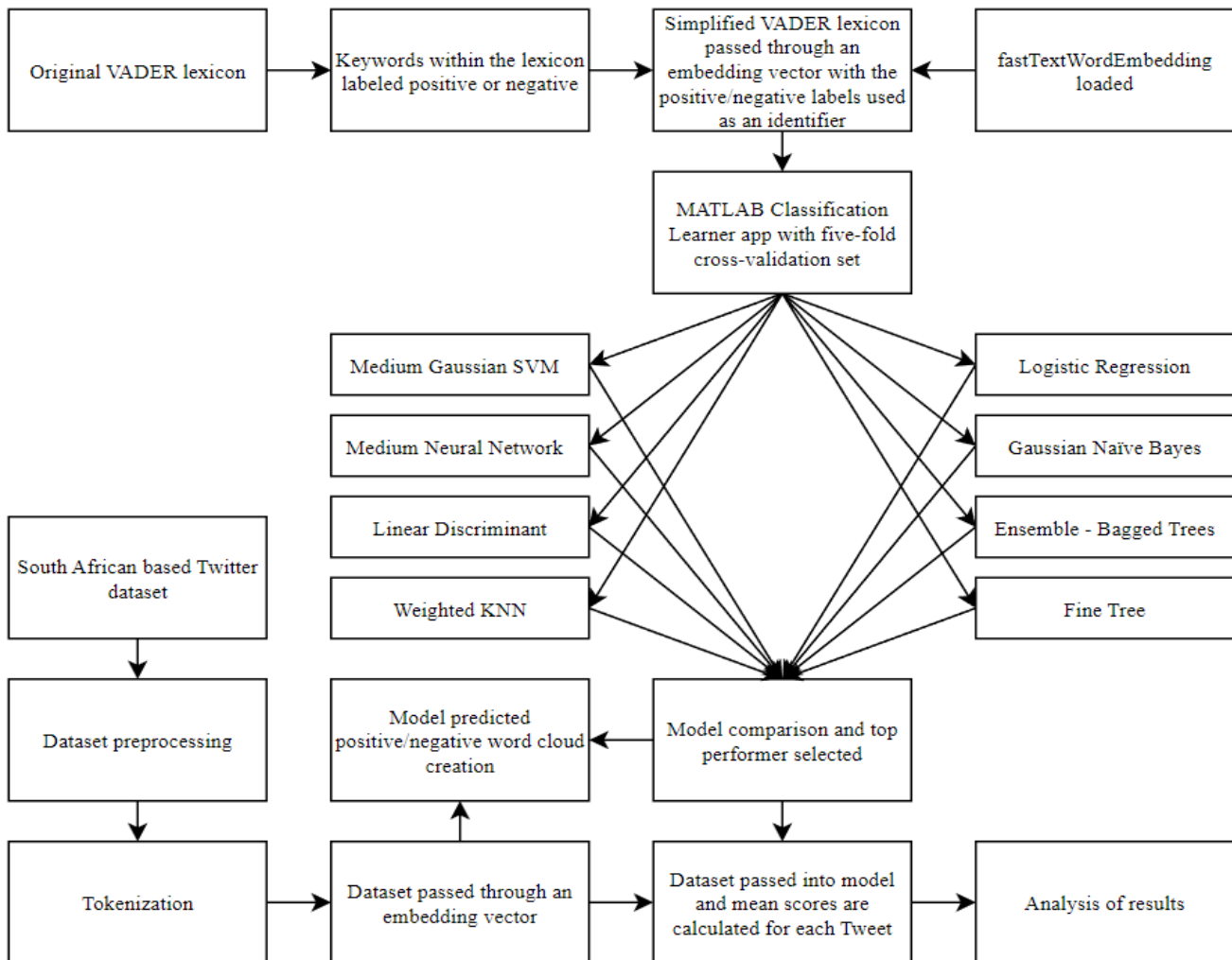


Fig. 1. The study architecture.

Vectorizing the simplified VADER Lexicon - A subfunction of the fastTextWordEmbedding function in MATLAB, word2vec is obtained via the "text analytics toolbox". The need to pass the simplified lexical corpus through word vectoring originates from distributed representation; the function assists in passing the words into numerical vectors [34], which assist the algorithm to better correlate words with their planned outcome.

Reconnecting the sentiment and the lexical vector - The linked sentiment is substituted as the vector's "predictor" after the lexical keywords have been vectorized.

Learner application for MATLAB classification - To check the generalization capacity of predictive models and avoid overfitting, the transformed lexicon is entered into the MATLAB classification learner program, and the validating method is set to five-fold cross-validation.

Training the machine learning models - The various hybrid models are created from a selection of classical models from the MATLAB classifier learner program. The chosen classical models are: Fine tree (FT), Medium Neural Network (MNN), Logistic Regression (LR), Gaussian Naive Bayes (GNB), MGSVM, Linear Discriminant (LD), Weighted K Nearest Neighbor (WKNN) and Ensemble-Bagged Trees (EBT). The models were programmed to make use of parallel processing. Table I highlights the parameters used to train each of the models. Additionally, hyperparameter options and principal component analysis was disabled for all the chosen models. The various models ran on default parameters, assigned to each model based on the way in which MATLAB interpreted the training dataset.

Having trained the various classical models on the VADER lexicon, the various hybrid models are compared using the following performance metrics: Validation confusion matrix (VCM), Accuracy, Recall, Precision, Receiver Operating Characteristic (ROC) curve, Area Under the Curve (AUC), F1-score, training time, and prediction speed.

### B. Stage 2 - An Overview of how the Hybrid Model was Utilized to Process the ZA Public Twitter Dataset:

Obtaining a Twitter based ZA public opinion dataset - The dataset of ZA public Twitter opinion is regarded as crucial for carrying out the experiment and creating a suitable environment. Because the presence of any manipulation could skew the results and compromise the authenticity of the simulated environment, the dataset must include the raw text from users' Tweets. This dataset might be retrieved through a selection of internet-based data repository sources, for instance "Kaggle," or it could be retrieved by leveraging the Twitter research Application programming interface (API) through an authorization process. As the researcher was unable to secure Twitter research API access, the dataset used in this article was obtained through Kaggle.

Data preparation - This part of the research entails processing the dataset into a suitable state for the trained hybrid model to process and output an authentic result.

TABLE I.        MATLAB CLASSIFICATION LEARNER MODEL PARAMETERS

| MATLAB Preset | Other |
|---|---|
| Medium Gaussian SVM (MGSVM) | Kernal function: Gaussian<br>Kernal scale: 17<br>Box constraint level: 1<br>Multiclass method: One-vs-One<br>Standardize data: true<br>Cost matrix: default |
| Medium Neural Network | Number of fully connected layers: 1<br>First layer size: 25<br>Activation: ReLU<br>Iteration limit: 1000<br>Regularization strength ($\lambda$): 0<br>Standardize data: yes |
| Linear Discriminant (LD) | Covariance structure: Full<br>Cost matrix: default |
| Weighted KNN (WKNN) | Number of neighbors: 10<br>Distance metric: Euclidean<br>Distance weight: squared inverse<br>Standardize data: true<br>Cost matrix: default |
| Logistic Regression (LG) | None |
| Naive Bayes (GNB) | Distribution name for numeric predictors: Gaussian<br>Distribution name for categorical predictors: N/A<br>Cost matrix: default |
| Bagged Trees (EBT) | Ensemble method: bag<br>Learner type: Decision tree<br>Maximum number of splits: 6092<br>Number of learners: 30<br>Cost matrix: default |
| Fine Tree (FT) | Maximum number of splits: 100<br>Split criterion: Gini's diversity index<br>Surrogate decision splits: off<br>Cost matrix: default |

- Removing columns - The Kaggle sourced Twitter dataset holds columns such as - "Tweet author", "Tweet created at", "Tweet coord", "Tweet favorite count", "Tweet hashtag", "Tweet retweet count", "Tweet place", and "Unique ID" - that are deemed extraneous. All irrelevant columns are eliminated, leaving the column "tweet text," which contains the textual data required.

- Erasing hexadecimal Unicode - The Kaggle obtained dataset was originally extracted by the author (Mbuso Makitla) utilizing the Tweepy API. Due to decryption limitations and time constraints, the MATLAB function "regexprep(str,expression,replace)" is used to remove the Unicode, with the "expression" and "replace" values of '\\[a-z0-9]3}' and ' respectively'.

- URL removal - To exclude URLs from the Twitter text, the erase URL (str) function in MATLAB is used. These occurrences usually happened because of Tweet authors retweeting or linking to other websites within their Tweets.

- Stop word elimination – According to [5] common phrases like "an", "it", and "the" are removed. The function removeStopWords(documents) in MATLAB is used to accomplish this. This is necessary to mitigate the consequences of noisy data.

- Normalization - This phase involves removing punctuation using MATLAB's erasePunctuation(str)

function, furthermore lower(str) is used to transform all Tweet text to lower case. The goal of normalization in the preprocessing stage is to increase text homogeneity [35].

- Tokenization - This is used to break down Tweets into smaller text samples for sentiment analysis; word tokenization is leveraged as the text is evaluated on a per word basis.

Using word2vec to transform the preprocessed ZA Twitter dataset – To produce distributed word representations, and to match the database to the training dataset, word2vec was used on the preprocessed ZA Twitter dataset.

Word cloud evaluation - This visual tool is leveraged to roughly assess the classificational ability of the hybrid model. The word cloud outputs assumptions for those words on which the hybrid model was trained, and new words the hybrid model has yet to encounter. The compilation of the word cloud is based off words contained in the ZA Twitter dataset.

Hybrid model implementation - The hybrid classifier is used once again to run the preprocessed ZA Twitter dataset. The classifier calculates the sentiment of each word in the Tweet and the segment of code thereafter assigns a mean score to the entire text sample. The outcome is responsible for determining the polarity of the text, negative values equate to negative sentiment as does a positive value indicate positive sentiment. Naturally the closer the sample is to zero the more neutral the Tweet text.

Sentiment analysis system evaluation – A function in MATLAB is leveraged to record the duration required to run the preprocessed ZA Twitter dataset through the hybrid model. Additionally, the final estimated outcome of the hybrid classifier and original Tweet is to lightly undergo a comparative observational analysis. This comparative analysis helps to identify instances where the hybrid model may have succeeded, misjudged, or failed to appropriately determine the sentiment of the Twitter text.

## IV. RESULT ANALYSIS

### A. A Comparison of the Various Created Hybrid Models:

The True Positive (TP) value serves as an indicator of the successful positive predictions made by the various hybrid models, as indicated in Fig. 2. The leading hybrid model (MGSVM) surpasses the runner-up (MNN) by a margin of 64 predictions. The False Positive (FP) value denotes how many positive samples the various hybrid models predicted incorrectly, as indicated in Fig. 2. The leading hybrid model (MGSVM) predicts more accurately than the runner-up (EBT) by a margin of 58 less incorrect predictions. The False Negative (FN) value indicates how many negative samples the various hybrid models predicted incorrectly, as indicated in Fig. 2 The MGSVM hybrid model makes fewer prediction errors than the runner-up (MNN) by a margin of 64 less inaccurate predictions. The True Negative (TN) value serves as an indicator of the successful negative predictions made by the various hybrid models, as indicated in Fig. 2. Where the MGSVM hybrid model surpasses the runner-up (EBT) by a margin of 58 predictions. In terms of VCM performance, the

MGSVM hybrid model is undoubtedly the winning hybrid model – as it outshone the remaining hybrid models in all four VCM categories. However, it is important to note that in the runner-up category, MNN (second best for TP and FN) was bested by EBT in the FP and TN categories FN, however EBT almost placed last in the TP and FN categories - this suggests that the MNN hybrid model is the rightful runner-up to the MGSVM hybrid model. Subject to a larger training dataset, the EBT algorithm does have the possibility of excelling, but the likelihood is that the EBT algorithm would continue to call an excessive number of values - negative. The WKNN and EBT hybrid model share similar patterns despite the different degree of extremes, which means the WKNN hybrid model may also possibly benefit from a lager training dataset. A possible cause of the labelling bias may stem from the fact that the VADER dataset contains 829 more negative than positive samples, this translates to a skew of 55.51% negative to 44.49% positive.
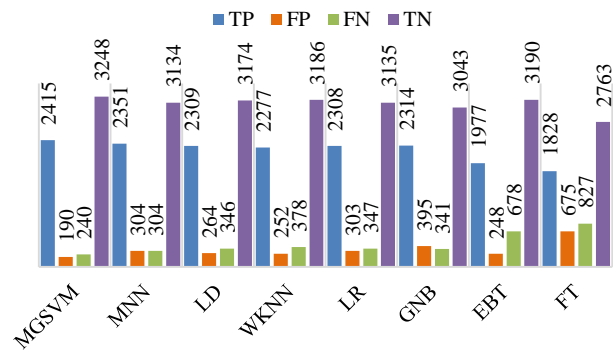


Fig. 2. A grouped bar chart comparing the VCM values of the eight hybrid models.

Table II holds performance metrics such as: accuracy, precision, recall and f1-score. These metrics are a resultant of calculations derived from VCM values. Table II additionally highlights the dominant stance the MGSVM hybrid model holds in every category in comparison to the several other hybrid models. The MGSVM hybrid model generates: an accuracy lead of 2.9% in comparison to the runner-up MNN; a precision of 92.7%, which in turn corresponds to a substantial contrast of 2, 7% in comparison to WKNN at 90%; a recall difference of 2.5% in comparison to the runner-up MNN at 88.5%; and finally, a specificity ratio at 0,945, in comparison to the runner-up EBT at 0,928.

TABLE II. THE PERFORMANCE EVALUATION METRICS FOR THE EIGHT HYBRID MODELS

| Model | Accuracy (%) | Precision | Recall | Specificity | F1-Score |
|---|---|---|---|---|---|
| MGSVM | 92,9 | 0,927 | 0,910 | 0,945 | 0,918 |
| MNN | 90,0 | 0,885 | 0,885 | 0,912 | 0,885 |
| LD | 90,0 | 0,897 | 0,870 | 0,923 | 0,883 |
| WKNN | 89,7 | 0,900 | 0,858 | 0,927 | 0,878 |
| LR | 89,3 | 0,884 | 0,869 | 0,912 | 0,877 |
| GNB | 87,9 | 0,854 | 0,872 | 0,885 | 0,863 |
| EBT | 84,8 | 0,889 | 0,745 | 0,928 | 0,810 |
| FT | 75,3 | 0,730 | 0,689 | 0,804 | 0,709 |

When compared to the other hybrid models, the MGSVM hybrid model is the overall best performer in the F1-score category – at 91.8% it secures a marginal triumph of greater than 3%. Following the MGSVM hybrid model in the F1 performance metric was MNN at 88.5% and LD at 88.3%. Comparatively the FT hybrid model performed terribly and only achieved an F1-score of 70.9%.

The ROC curve serves as a graphical representation of the relationship between the TP rate and FP rate indices of a model. It additionally serves as a visual means of assessing the model's diagnostic capacity. The MGSVM hybrid model steadily outperforms the other hybrid models, as seen in Fig. 3. MNN, LD, WKNN, and LR, the middle runners, are all close to each other. Furthermore, falling just short of the middle runners is the GNB hybrid model, and despite the smooth curve, the EBT hybrid model lags to an even greater extent. Finally, the FT hybrid model curve shows how the slow to train and erratically the hybrid model behaves as it places in the last position.
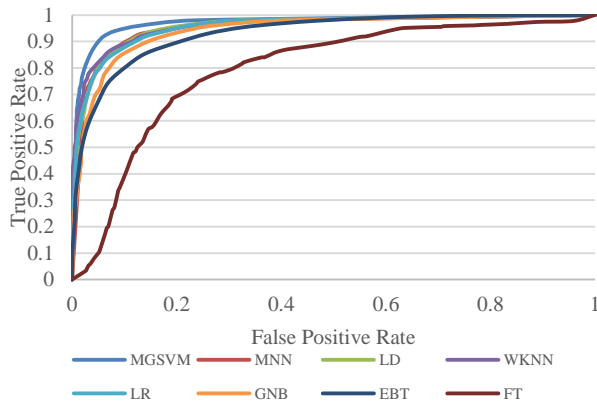


Fig. 3. The ROC curve of the eight hybrid models.

The area beneath the ROC is also of great importance as larger AUC values are often desired and this number falls between 1 and 0. Fig. 3 shows the superior area beneath the curve which the MGSVM hybrid model holds, and subsequently has a very good AUC score of 0.98 as per Fig. 4. The majority of the other hybrid models fall between 0.95 and 0.93, resulting in a minimum 0.02 deficit in favor of the MGSVM hybrid model. At 0.79, FT performs dismally once more. Fig. 4 highlights both the AUC, and the "co-ordinates" where the "current classifier" point exists on the ROC in Fig. 3, although not depicted; these co-ordinates may be found along the columns labelled "True Positive Rate" and "False Positive Rate".

As presented in Table III, each hybrid model furnished generic training results with metrics, such as 'total misclassification cost' and 'prediction speed'. The entire misclassification cost of the MGSVM hybrid model was 430, and the forecast speed was approximately 7, 5 objects per millisecond.
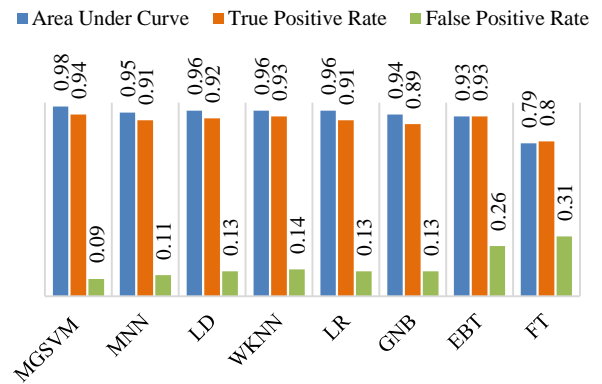


Fig. 4. AUC, TP, and FP rate of all hybrid models.

TABLE III. ADDITIONAL GENERAL HYBRID MODEL TRAINING RESULTS

| Created Hybrid Model | Training Results (General) | |
|---|---|---|
| | *Total Misclassification Cost* | *Prediction speed (objects/milliseconds)* |
| MGSVM | 430 | ~7,5 |
| MNN | N/A | ~72 |
| LD | 610 | ~23 |
| WKNN | 630 | ~1 |
| LR | N/A | ~25 |
| GNB | 736 | ~45 |
| EBT | 926 | ~22 |
| FT | 1502 | ~43 |

Training time – another important model value – is predominantly evaluated in two scenarios: firstly, a constant supply of emerging data which in turn leads to frequent retraining of the model; secondly, more complex or lager datasets can also lead to a dramatic increase in training times. Due to the use of the smaller simplified VADER corpus, training time is less of a concern in comparison to a larger lexicon, such as SentiWordNet, which includes around 117000 keywords.

Fig. 5 shows the LD hybrid model was trained in a mere 5, 18 seconds – making it undoubtedly the quickest to train in this instance. Second to this was GNB at 9,39 seconds followed by LR at 12,12 seconds. The favored MGSVM hybrid model achieved fifth position at 23,78 seconds. Following from here onward the training times of the other hybrid models, except for the FT hybrid model, rapidly deteriorated to approximately the 70-80 second domain. Keeping the context of the study in mind, training times would only be relevant should the dataset: grow in some way; be replaced by the production or disclosure of a larger more suitable lexical dataset; or require frequent retraining. In the context of training time, the LD hybrid model may only be worth taking into consideration as a backup option should it not require frequent retraining, as it is not susceptible (more so than other hybrid models) to dramatic increases in training time (relative to the size of the new dataset) or should the MGSVM hybrid model fail. Finally, one can concur that

the MGSVM is more than acceptable for this application, because of the one-time training requirement and a more than bearable training duration.

### B. Hybrid Model Performance Regarding Twitter Dataset Sentiment Analysis:

Pre-processing the ZA public Twitter dataset was determined as a straightforward task that was successfully completed. Prior to allowing the MGSVM hybrid model to determine the sentiment of the pre-processed ZA public Twitter dataset, it was crucial to consider how the hybrid model will handle both in terms of data it had encountered and that in which it hadn't. Fig. 6 shows two-word clouds: the one on the left highlights terms that the hybrid model predicts will have a positive opinion, while the one on the right highlights phrases that the hybrid model predicts will have a negative emotion. This step is crucial as it allows for basic visual conformation that the hybrid model is behaving reasonably and within expected range when judging sentiment for both words it has yet to encounter, as well as those contained within the lexical corpus training dataset.

As per the positive word cloud in Fig. 6, it is observed that the hybrid model correctly classified most new terms supplied as positive. For instance, enriching, excellence, happy, inspirational, and wholesome have an undeniably positive connotation. However, there were several unusual predictions made by the hybrid model:

- Kelly - a proper noun used to provide someone/something a name. Due to the lack of emotion behind the word it remains commonly regarded as neutral.

- Cuppa - a traditionally British colloquialism for "a cup of tea". It does not feature in the VADER lexicon; however, it tends to carry a positive sentiment.

- Polo - a term that refers to either an equestrian sport or a popular Volkswagen automobile model. Although traditionally the word is neutral, the positive sentiment may have incorrectly been derived from either apology or one of its derivatives that VADER deems a positive term - the derivative "apologizing" is the only derivative seen as negative.
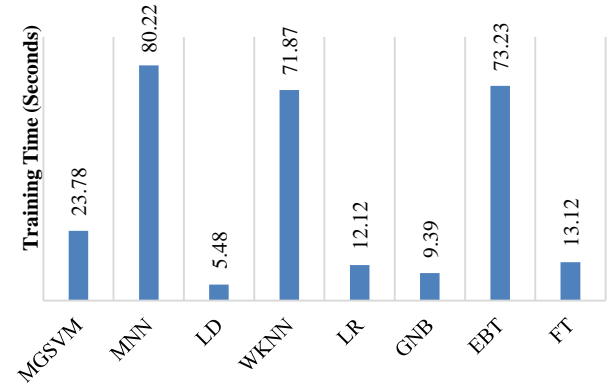


Fig. 5.    A hybrid model training time comparison.
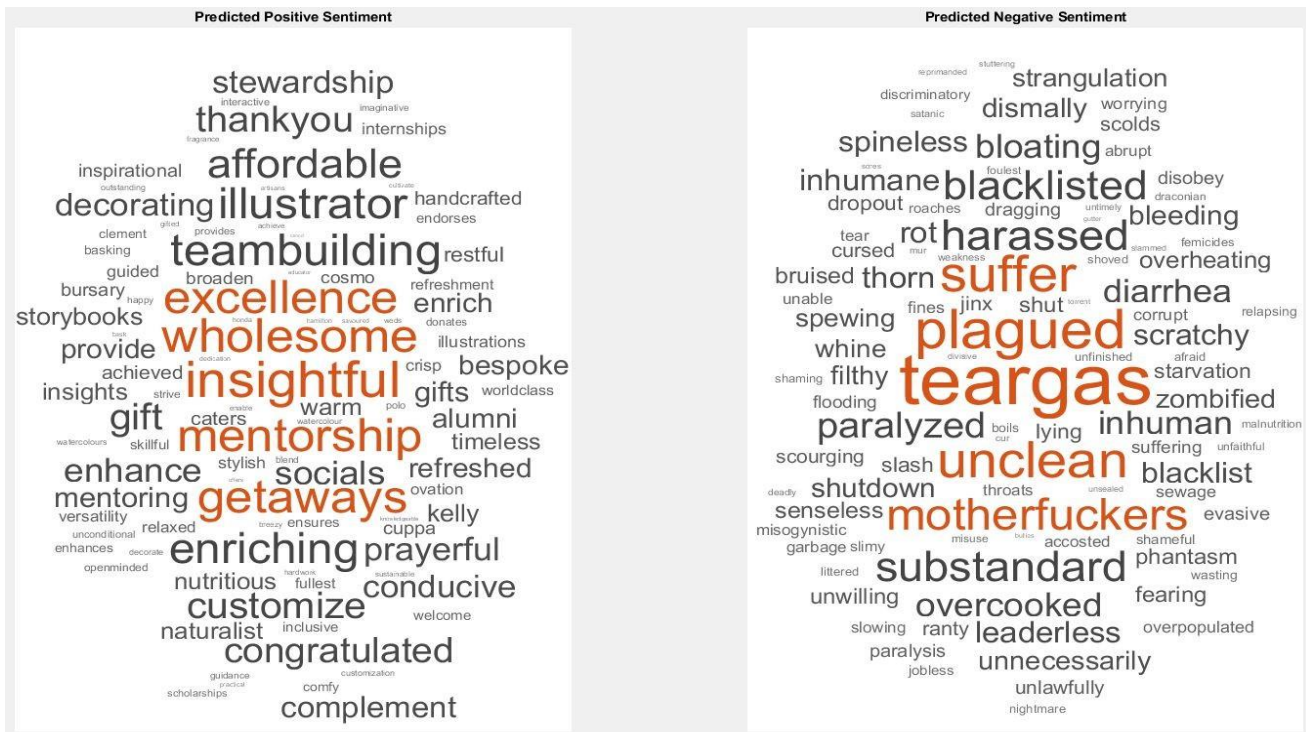


Fig. 6.    A word cloud containing words of positive (left) and negative (right) sentiment that the hybrid model has labelled from the ZA Twitter public dataset.

The word cloud consisting of 'positive' words tended to contain terms of a predominantly positive nature - with only a few neutral exceptions. It did not contain any negative words.

Observably the negative word cloud in Fig. 6, highlights that the hybrid model correctly classified most of the new terms provided as negative. Corrupt, inhumane, misogynistic, plagued, and suffer are all words that have a negative connotation. Only words with a negative emotional context were found to be in the 'negative' word cloud, with no discernible words of a neutral or positive nature detected. That said, an argument could be made that the 'negative' word cloud contained a few words that held contextually varying sentiment. This can be demonstrated with the word "cut", which should appear as neutral in "my new knife has a brilliantly clean cut." Considering the word "cut" as negative in this context risks throwing the sentiment of a clearly positive string of text into an overall neutral result.

After successfully running the pre-processed ZA public Twitter dataset through the MGSVM hybrid model, the results were further processed utilizing an aggregate scoring technique to achieve document-level sentiment analysis – that output a resultant Tweet sentiment score. Overall, it took 45 minutes and 25 seconds to run the hybrid model on the entire pre-processed ZA public Twitter dataset (67585 total Tweets) to get the mean sentiment of each Tweet.

## V. DISCUSSION

The hybrid model identified the below five Tweets in the dataset as the most positively oriented in terms of prediction efforts (any duplicate Tweets by users are ruled out):

- "Neymar enjoying his @redbull https://t.co/rb1JxQiIct" – Perceivably positive. Neymar is pictured in the post as being in a celebratory mood posing with an energy drink.

- "Thank you @shotsbysbu this is so beautiful #bbnajia2020 #SSDiski #MotoGP https://t.co/NJ6kAClvdq" – Perceivably positive. The Twitter shortened link leads to the image of a wonderful art piece that the author refers to.

- "Together with her beauty #SkeemSaam https://t.co/I99y40BxUP" – Perceivably positive. The author further complements and connects with a Twitter shortened link, to which another Twitter user encourages the wedlock of a TV personality.

- "Children? Goodluck https://t.co/Y3FPLJkwmA" – Perceivably negative. The author is either implicating that complex matters may be difficult to educate children on, or alternatively believes the Twitter linked author has had a lapse of judgement for wanting to educate their children about the LGBTQI+ community. The hybrid model can only analyze the textual component and is unable to study the context required from the additional Twitter shortened link, resulting in the prediction error.

- "This is nice. #CouplesDay https://t.co/AeEaNPIGA4" – Perceivably positive. The author expresses enthusiasm towards couple's day. Although doubtful, the term of phrase "This is nice." could also be taken sarcastically. However, there are no grounds to support either assertion as the URL is no longer available.

The hybrid model identified the below five Tweets in the dataset as the most negatively oriented in further prediction efforts (once again, any duplicate Tweets by users are ruled out):

- "Neymar the Dangerous https://t.co/np6RzEMoxp" – Perceived as either negative or positive. The author is either a fan or an oppositional critic of Neymar, a professional football athlete. The link leads to an image showing Neymar in possession of the ball and closely surrounded by three oppositional players. The hybrid model is clearly focused on the negative connotation of the term dangerous. Due to the inability to further explore image sources the hybrid model is unable to gain greater contextual understanding.

- "YOU ARE CURSED https://t.co/ftP4t4eG0y" – Perceivably negative. The Tweet author is damning another user. The original Tweet author implies that the author in the link is possessed, as they would like to begin teaching children about homosexuality from the age of seven.

- "Mama boyza she lying jerrrrrrr #SkeemSaam" – Perceivably negative. The author is upset and frames a female character on the TV show "Skeem Saam" as dishonest.

- "Wow, Im sad #RIPNdlovu" – Perceivably Negative. The author is grieving the loss of a figure in their lives.

- "Zimbabwe. We are in trouble. #PutSouthAfricansFirst. #SAMediaMustFall https://t.co/EPo3JS4E4N" – Perceivably Negative. The author may share a negative sentiment with the link's author, who is concerned about the asylum issue and believes that South Africa suffers the brunt of the responsibility.

The below Tweets were deemed neutral by the hybrid model, despite the positive sentiment intended by the author:

- "Same. https://t.co/xesDjgfA4d" – Perceivably positive. The author and link author share the same mindset to teach their children about relationships and the LBGTQI+ community. Due to model limitations, the hybrid model has no further context and the Tweets main text "Same." ends up taking on a neutral sentiment.

- "Saving this https://t.co/354EU4auV1" – Perceivably positive. The author agreeingly feels that educating their children about homosexuality and relationships is essential, hence the desire to save the content for future reference. The term "saving this" is interpreted as neutral by the hybrid model as it is unable to further explore the contents behind the Twitter shortened link.

The below Tweets were deemed neutral despite the hybrid model having acquired clear direction in the training dataset:

- "Thank you @chrishemsworth https://t.co/VCFxtYuYLG #motivate #sundaymotivation #covid" – Perceivably positive. The author is thanking a famous film actor via their Twitter handle and using hashtags of a positive nature, except for "#covid" which has a negative stigma. Even though the hybrid model had previously identified, within the positive word cloud, the closed compound word "thankyou", the inability of the hybrid model to further perceive the open compound of "thank you" as positive is uncertain.

- "Wtf is this? https://t.co/hffp9iOFBU" – Perceived as either negative or positive. The author is confronted by the image of a French Poodle on a red sofa followed by the heading "nothing to see here", this method of notifying a user of a missing page is done by Twitter to try and lift the users' spirits. In this instance the author might use the phrase "Wtf is this?" as a positive means to show their followers the amusing content. Alternatively, the author may be frustrated by the missing content hence the use of "Wtf". Further analysis reveals that the acronym 'wtf' is classified as negative in the VADER lexicon, as to why the Tweet was deemed as neutral is a mystery.

## VI. LIMITATIONS

Throughout the research several limitations were discovered, this is to be expected. Effort was made to overcome several of the limitations – however the list below highlights unresolved limitations faced:

- Twitter API access and the use of a publicly available dataset. Despite numerous attempts the researchers could not gain research access to the Twitter API, this meant that a publicly available dataset became the next best available option. However, the use of a publicly available dataset means that search selection criteria are lost, and one could argue that it leads to an imperfect artificial environment for model testing.

- Punctuation removal. Certain entries in the VADER lexicon are punctuation based emojis. Additionally, the general use of punctuation adds to sentiment. The removal of punctuation resultantly leads to a loss in sentiment.

- Twitter dataset Hexadecimal Unicode removal. Aside from punctuation based emojis which were ultimately removed, the VADER dataset does not contain any hexadecimal Unicode emojis. The removal of hexadecimal Unicode, however, ultimately results in a loss of sentiment when assessing the Twitter dataset.

- The removal of certain words that do not appear in the isVocabularyWord subfunction of the function fastTextWordEmbedding. To effectively use the word2vec subfunction in MATLAB textual data should pass through the isVocabularyWord subfunction. However, passing certain misspelled, unknown slang, or other forms of other unknown words – means that

they are eradicated from both the training dataset and the tested Twitter dataset.

- Lack of contextual inclusion. Despite Twitter predominantly being a text-based platform, social media contains text, images, videos, and URLs. These other forms of medium are unreadable by a text-based sentiment analysis model.

## VII. CONCLUSION

The research evaluated several hybrid sentiment analysis models, of which a state-of-the-art simplified VADER centered hybrid sentiment analysis model was produced. In accordance with the results, the MGSVM hybrid model outperformed the other hybrid models by a significant margin. Training time was identified as the key disadvantage of the MGSVM hybrid model creation process, demonstrated to be inconsequential in the future as instances of retraining would be rare and the use of a more expansive and/or intricate corpus was not a necessity. Additionally, the LD, LR, MNN, WKNN, and GNB hybrid models, albeit the latter to a lesser extent, were among the middle runners. By far the FT hybrid model was deemed as the poorest performer amongst the hybrid models. The chosen MGSVM-VADER hybrid proved to be highly effective when applied to a ZA Public Twitter opinion dataset. Ultimately, the research question "Will the MGSVM-VADER hybrid model approach produce accurate sentiment analysis of public Twitter opinion in South Africa?" was in turn effectively answered.

## VIII. FUTURE WORK

The following work would build upon the MGSVM-VADER hybrid in this study. A specialty language/slang modified VADER lexicon poses as a research possibility for a particular future audience. The creation of a system that also considers emojis, hexadecimal Unicode, and punctuation, and then translates them into the textual equivalent to be used with purely text-based sentiment analysis models. Additionally, the creation of a contextually aware hybrid sentiment analysis model – that could possibly explore subject matter behind URL links, videos, and images – could be an interesting future prospect.

### DATA AVAILABILITY

The full VADER Dataset is available online at: https://github.com/cjhutto/vaderSentiment/blob/master/vaderSentiment/vader_lexicon.txt.

The SA Twitter dataset is available online at: https://www.kaggle.com/mbusomakitla/south-african-twitter-dataset.

### CONFLICTS OF INTEREST

The authors declare that there are no conflicts of interest.

REFERENCES

[1] F. Neri, C. Aliprandi, F. Capeci, M. Cuadros, and T. By, "Sentiment analysis on social media," in Proceedings of 2012 IEEE/ACM International Conference on Advances in Social Networks Analysis and Mining. IEEE, pp. 919-926. 26-29 August 2012.

[2] R.M. Alguliyev, R.M. Aliguliyev, and G.Y. Niftaliyeva, "Extracting social networks from e-government by sentiment analysis of users' comments," Electronic Government, an International Journal, 15(1), pp. 91-106. 2019.

[3] A, Corallo, L. Fortunato, M. Matera, M. Alessi, A. Camillò, V. Chetta, E. Giangreco, and D. Storelli, "Sentiment analysis for government: An optimized approach," in Proceedings of International Workshop on Machine Learning and Data Mining in Pattern Recognition. Springer, pp. 98-112. 2015

[4] S. Verma, "Sentiment analysis of public services for smart society: Literature review and future research directions," Government Information Quarterly, 39(3), 101708. 2022.

[5] O. Alqaryouti, N. Siyam, A.A. Monem, and K. Shaalan, "Aspect-based sentiment analysis using smart government review data," Applied Computing and Informatics, 2020.

[6] F. Hemmatian and M.K. Sohrabi, "A survey on classification techniques for opinion mining and sentiment analysis," Artificial intelligence review, 52(3), pp. 1495-1545. 2019.

[7] Y. Wang, Y. Rao, and L. Wu, "A review of sentiment semantic analysis technology and progress," in proceedings of 2017 13th International Conference on Computational Intelligence and Security (CIS). IEEE, 452-455. 15-18 December 2017.

[8] E. Kotzé and B. Senekal, "Employing sentiment analysis for gauging perceptions of minorities in multicultural societies: An analysis of Twitter feeds on the Afrikaner community of Orania in South Africa," TD: The Journal for Transdisciplinary Research in Southern Africa, 14 (1), pp. 1-11, 2018.

[9] J. Oyasor, M. Raborife, and P. Ranchod, "Sentiment analysis as an indicator to evaluate gender disparity on sexual violence tweets in South Africa," in proceedings of 2020 International SAUPEC/RobMech/PRASA Conference. IEEE, pp. 1-6, 29-31 January 2020.

[10] Y. Khan, "A longitudinal sentiment analysis of the# FeesMustFall campaign on Twitter," diss, 2019.

[11] H. Sims, "Public confidence in government, and government service delivery," Citeseer, 2001.

[12] E. Isin and E. Ruppert, "Being digital citizens," Rowman & Littlefield Publishers, 2020.

[13] M. Birjali, M. Kasri, and A. Beni-Hssane, "A comprehensive survey on sentiment analysis: Approaches, challenges and trends," Knowledge-Based Systems, 226, p.107134. 2021

[14] M.H. Abd El-Jawad, R. Hodhod, and Y.M. Omar, "Sentiment analysis of social media networks using machine learning," in proceedings of 2018 14th international computer engineering conference (ICENCO). IEEE, pp. 174-176. 29-30 December 2018.

[15] C.J. Varshney, A. Sharma, and D.P. Yadav, "Sentiment Analysis using Ensemble Classification Technique," in proceedings of 2020 IEEE Students Conference on Engineering & Systems (SCES). IEEE, pp. 1-6, 10-12 July 2020.

[16] O. Araque, I. Corcuera-Platas, J.F. Sánchez-Rada, and C.A. Iglesias, "Enhancing deep learning sentiment analysis with ensemble techniques in social applications," Expert Systems with Applications, 77, pp. 236-246, 2017.

[17] D. Tiwari and B. Nagpal, "Ensemble Methodsof Sentiment Analysis: A Survey," in proceedings of 2020 7th International Conference on Computing for Sustainable Global Development (INDIACom). IEEE, pp. 150-155, 12-14 March 2020.

[18] J. Dou, A.P. Yunus, D.T. Bui, A. Merghadi, M. Sahana, Z. Zhu, C.W Chen, Z. Han, and B.T. Pham, "Improved landslide assessment using support vector machine with bagging, boosting, and stacking ensemble machine learning framework in a mountainous watershed, Japan," Landslides, 17 (3), pp, 641-658, 2020.

[19] R. Kashef, "A boosted SVM classifier trained by incremental learning and decremental unlearning approach," Expert Systems with Applications, 167, p.114154, 2021.

[20] J.Y. Huang, W.P. Lee, and K.D. Lee, "Predicting Adverse Drug Reactions from Social Media Posts: Data Balance, Feature Selection and Deep Learning," Healthcare, 10(4), p. 618, MDPI. 2022.

[21] F. Alzamzami, M. Hoda, and A. El Saddik, "Light Gradient Boosting Machine for General Sentiment Classification on Short Texts: A Comparative Evaluation," IEEE Access, 8, pp.101840-101858, 2020.

[22] M. Khalid, I. Ashraf, A. Mehmood, S. Ullah, M. Ahmad, and G.S. Choi, "GBSVM: Sentiment Classification from Unstructured Reviews Using Ensemble Classifier," Applied Sciences, 10(8), p. 2788, 2020.

[23] A. Alrehili and K. Albalawi, "Sentiment analysis of customer reviews using ensemble method," in 2019 International conference on computer and information sciences (ICCIS), pp. 1-6, IEEE. 03-04 April 2019.

[24] N. Sultana and M.M. Islam, "Meta classifier-based ensemble learning for sentiment classification," in proceedings of International Joint Conference on Computational Intelligence, pp. 73-84, Springer. 2020.

[25] B. Ray, A. Garain, and R. Sarkar, "An ensemble-based hotel recommender system using sentiment analysis and aspect categorization of hotel reviews," Applied Soft Computing, 98, p.106935, 2021.

[26] L. Zhao, L. Li, X. Zheng, and J. Zhang, "A BERT based sentiment analysis and key entity detection approach for online financial texts," in proceedings of 2021 IEEE 24th International Conference on Computer Supported Cooperative Work in Design (CSCWD), pp. 1233-1238, IEEE, 05-07 May 2021.

[27] N. Zainuddin, A. Selamat, and R. Ibrahim, "Hybrid sentiment classification on twitter aspect-based sentiment analysis," Applied Intelligence, 48, pp. 1218-1232, 2018.

[28] S. Mendon, P. Dutta, A. Behl, and S. Lessmann, "A hybrid approach of machine learning and lexicons to sentiment analysis: Enhanced insights from twitter data of natural disasters," Information Systems Frontiers, 23, pp. 1145-1168, Springer, 2021

[29] Y. Al Amrani, M. Lazaar, and K.E. El Kadiri, "A Novel Hybrid Classification Approach for Sentiment Analysis of Text Document," International Journal of Electrical & Computer Engineering, 8(6), pp. 4554-4567, 2018.

[30] X. Jiang, "Isolated Chinese sign language recognition using gray-level co-occurrence matrix and parameter-optimized medium gaussian support vector machine," In Frontiers in Intelligent Computing: Theory and Applications, pp. 182-193. Springer, 2020

[31] SL. Lin, "Application of Machine Learning to a Medium Gaussian Support Vector Machine in the Diagnosis of Motor Bearing Faults," Electronics, 10(18), p. 2266, MDPI. 2021.

[32] C. Hutto and E. Gilbert, "Vader: A parsimonious rule-based model for sentiment analysis of social media text," in proceedings of the International AAAI Conference on Web and Social Media, 8(1), 2014.

[33] C.A. Ramezan, T.A. Warner, and A.E. Maxwell, "Evaluation of sampling and cross-validation tuning strategies for regional-scale machine learning classification," Remote Sensing, 11(2), p.185, MDPI. 2019.

[34] T. Mikolov, K.Chen, G. Corrado, and J. Dean, "Efficient estimation of word representations in vector space," arXiv preprint arXiv:1301.3781, 2013.

[35] R. Ahuja, A. Chug, S. Kohli, S. Gupta, and P. Ahuja, "The impact of features extraction on the sentiment analysis," Procedia computer science, 152, pp. 341-348, 2019.

# Analysis of Depression in News Articles Before and After the COVID-19 Pandemic Based on Unsupervised Learning and Latent Dirichlet Allocation Topic Modeling

Seonjae Been[1], Haewon Byeon[2]*

Department of Digital Anti-Aging Healthcare (BK21), Inje University, Gimhae 50834, South Korea[1]
Department of Medical Bigdata, Inje University, Gimhae 50834, South Korea[2]

*Abstract*—As of 2023, South Korea maintains the highest suicide rate among OECD countries, accompanied by a notably high prevalence of depression. The onset of the COVID-19 pandemic in 2020 further exacerbated the prevalence of depression, attributed to shifts in lifestyle and societal factors. In this research, differences in depression-related keywords were analyzed using a news big data set, comprising 45,376 news articles from January 1st, 2016 to November 30th, 2019 (pre-COVID-19 pandemic) and 50,311 news articles from December 1st, 2019 to May 5th, 2023 (post-pandemic declaration). Latent Dirichlet Allocation (LDA) topic modeling was utilized to discern topics pertinent to depression. LDA topic modeling outcomes indicated the emergence of topics related to suicide and depression in association with COVID-19 following the pandemic's onset. Exploring strategies to manage such scenarios during future infectious disease outbreaks becomes imperative.

*Keywords*—*COVID-19; depression; news articles; LDA topic modeling*

## I. INTRODUCTION

South Korea has consistently reported the highest suicide rate among OECD countries. Since 2004, South Korea has implemented a five-year suicide prevention plan called the Basic Plan for Suicide Prevention. However, the suicide rate in South Korea has remained the highest among OECD countries for an extended period, with a rate 2.2 times higher than the OECD average as of 2019 [1]. Previous studies have emphasized low treatment rates for depression as one of the causes of high suicide rates [2], indicating a significant number of individuals with depression in South Korea who do not receive treatment. Particularly, since the outbreak of COVID-19 in 2020, the prevalence of depression in South Korea has worsened. According to surveys conducted by Statistics Korea, while the pre-COVID-19 prevalence of depression was 20% [3], it increased nearly twofold to 36.8% after the COVID-19 pandemic [4].

The long-term COVID-19 pandemic has led to social changes in South Korea due to measures such as social distancing, reduced outings and gatherings, and economic difficulties [5]. As a result, issues such as social isolation due to disrupted social networks, economic hardships, weight gain, and concerns about COVID-19 infection spread have arisen [5]. These problems have had significant societal impacts in

South Korea to an extent that gave rise to a new term called "corona blue."

As described above, depression in South Korea has been exacerbated socially due to the COVID-19 pandemic. According to a study by Lee et al., there was an increase in incidence rates of depression and prevalence rates for moderate and severe depression after the COVID-19 pandemic outbreak [6]. Furthermore, during periods of high transmission rates like during outbreaks or when Omicron variant spread internationally, significantly higher levels of excess mortality were observed [7]. In other words, the COVID-19 pandemic has had substantial effects not only on depressive symptoms but also on increased suicide rates among individuals. This study aims to analyze changes in keywords related to depression before and after the COVID-19 pandemic using news big data from South Korea through unsupervised learning algorithms such as Latent Dirichlet Allocation (LDA) topic modeling. By identifying hidden topics within collections of words or documents and grouping them based on documents or keywords using LDA topic modeling technique this research visualized key issues related to depressive symptoms before and after the COVID-19 pandemic.

## II. RESEARCH METHODOLOGY

### A. Data Collection

To analyze news articles related to depression before and after the COVID-19 pandemic, we utilized the BIGKinds service provided by the Korea Press Foundation. BIGKinds is a news big data analysis service that allows for the analysis of social phenomena using structured text data. In this study, we collected data from a total of 26 media outlets, including 11 national daily newspapers, eight economic daily newspapers, five broadcasting companies, and two specialized magazines (see Table I).

This study aimed to investigate depression before and after the COVID-19 pandemic by searching for keywords such as "depression," "feeling depressed," "depressive symptoms," and "depressive disorder." The search was divided into two periods: before and after the COVID-19 pandemic. The analysis period was determined considering the introduction of the COVID-19 pandemic in South Korea and the declaration of

*Corresponding Author.

an endemic. The period before the COVID-19 pandemic was set from January 1, 2016, to November 30, 2019. The period after the COVID-19 pandemic was set from December 1, 2019, to May 5, 2023 (the date of endemic declaration). After excluding duplicate articles and those unrelated to the topic, a total of articles used for analysis is shown in Table II.

TABLE I.     MEDIA BIGDATA SET SUBJECT TO TABLE ANALYSIS

| Category (Number) | Daily newspaper name |
|---|---|
| National daily newspaper (11) | Kyunghyang Shinmun, Kookmin Ilbo, Naeil Shinmun, Donga Ilbo, Munhwa Ilbo, Seoul Shinmun, Segye Ilbo, Chosun Ilbo, JoongAng Ilbo, Hankyoreh, Hankook Ilbo |
| Economic daily newspaper (8) | Maeil Economy, Money Today, Seoul Economy, Asia Economy, Aju Economy, Financial News, Korea Economy, Herald Economy |
| Broadcasting company (5) | KBS, MBC, OBS, SBS, YTN |
| Professional journals (2) | Digital Times, Electronic Newspaper |

TABLE II.     NUMBER OF ARTICLES USED FOR ANALYSIS

| | Before the outbreak of COVID-19 pandemic | After the outbreak of COVID-19 pandemic |
|---|---|---|
| Total number of articles | 47,905 | 52,707 |
| Number of excluded articles | 2,529 | 2,396 |
| Number of analysis articles | 45,376 | 50,311 |

### B. Data Preprocessing

To investigate depression before and after the COVID-19 pandemic, we conducted keyword-based searches using combinations of terms such as "depression," "feeling depressed," and "depressive disorder." The analysis period was divided into two parts: pre-COVID-19 pandemic (from January 1, 2016, to November 30, 2019) and post-pandemic declaration (from December 1, 2019, to May 5, 2023), considering the timing of the COVID-19 outbreak in South Korea and the declaration of an endemic state. We excluded duplicate articles and those unrelated to the research topic.

### C. Analysis Method

The analysis in this study was conducted using Python and involved frequency analysis, TF-IDF (Term frequency–inverse document frequency), and LDA (Latent Dirichlet Allocation) topic modeling.

First, we analyzed the frequency of word occurrences based on the collected articles. Then, we used TF-IDF to evaluate the relevance of words to the articles [8]. Subsequently, LDA topic modeling was applied to analyze the main topics within the collected articles.

LDA is a generative probabilistic model developed by Blei et al. and is one of the most well-known topic modeling techniques [9-11]. LDA analyzes data based on words used in documents or text data. It assumes that there are several topics and randomly selects a distribution of topics. Each word is then extracted from one of the topics, which is selected from the distribution specific to each document [11]. Therefore, LDA

automatically discovers topics in documents and infers hidden semantic structures by outputting sets of words that have a high probability of co-occurrence within each topic [9-11].

### III. RESULTS

#### A. Network Analysis

The network analysis of the relationship between depression and related keywords before and after the COVID-19 pandemic is shown in Fig. 1, Fig. 2 and also in Table III. The network analysis provided by BIGKinds is based on the top 100 articles with the highest accuracy among search results. It extracts noun phrases and applies Structured SVM (Support Vector Machine) to assign weights considering the number of related articles [12]. In Fig. 1, weights ranging from 4 to 34 were applied, while in Fig. 2, weights ranging from 6 to 51 were applied.

Fig. 1 represents the network analysis of depression-related keywords before the COVID-19 pandemic. The top keyword identified in this analysis is "program." This keyword is associated with programs related to depression operated by local governments and the central government. Additionally, the relationship diagram shows that it is related to Okcheon County due to its implementation of a project called "Zero Depression" [13]. The relationships associated with workers and Asan City are attributed to a depression screening conducted as part of mental health initiatives for workers by Asan City. The results showed that Asan Police Station had the lowest depression score, while call center counselors at Asan City Hall had the highest depression score [14].

Fig. 2 represents the network analysis of depression-related keywords after the COVID-19 pandemic. The top three keywords identified in this analysis are "COVID-19," "Mental Health Welfare Center," and "Ministry of Health and Welfare." This suggests that there has been an increase in experiences of depressive feelings and the prevalence of depression due to various social changes resulting from the COVID-19 pandemic.

#### B. Frequency Analysis Results

The frequency analysis of depression-related words before and after the COVID-19 pandemic revealed that "depressive disorder" had the highest frequency in both periods. However, there were additional keywords related to the COVID-19 pandemic (such as "COVID-19 outbreak," "corona," "coronavirus") in the post-pandemic period. It can be observed that the frequency and weight of keywords related to the COVID-19 pandemic are higher.

#### C. LDA Topic Modeling

*1) LDA topic modeling design:* Using Python, we calculated the coherence score, as shown in Fig. 3. The coherence score is a metric used to determine the optimal number of topics to be set for topic modeling. The number of topics with the highest coherence score is considered appropriate. In this study, based on the coherence scores, we set seven topics for the pre-COVID-19 pandemic period and six topics for the post-pandemic period.
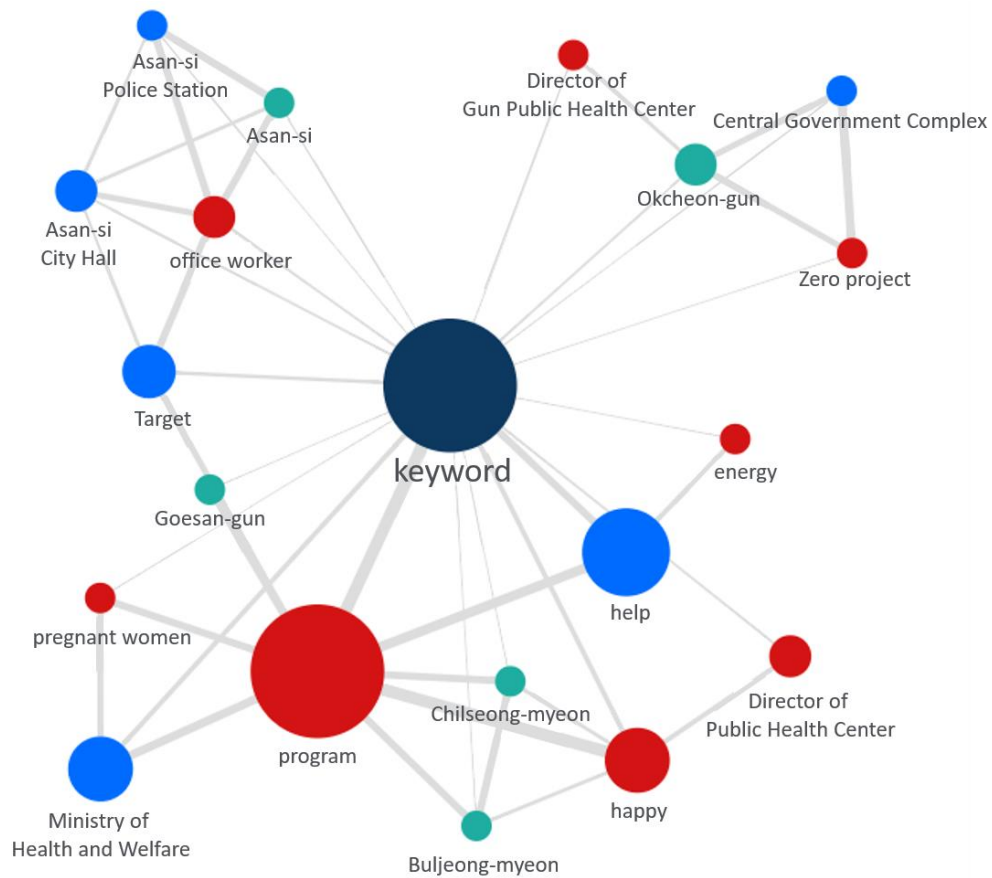
Fig. 1.    Keyword network analysis of depression before the COVID-19 pandemic.
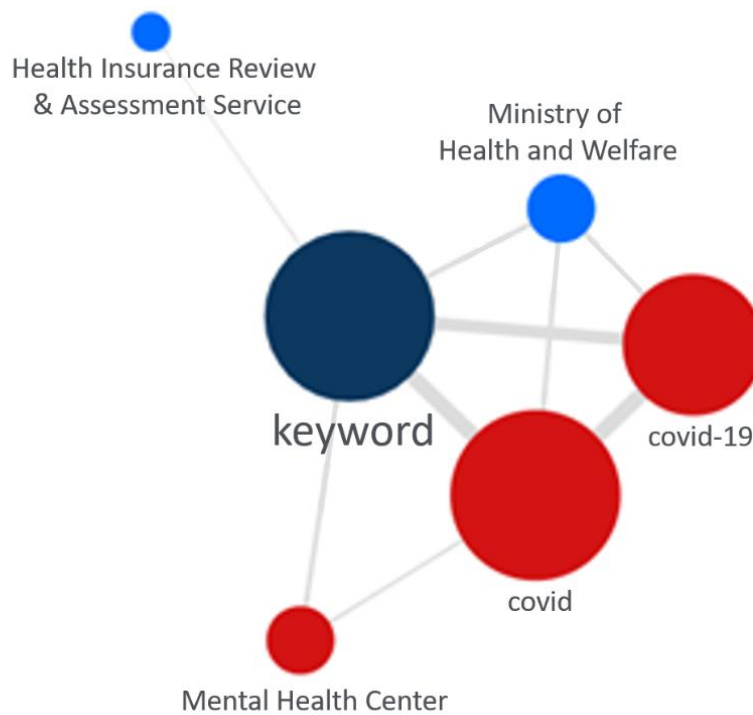


Fig. 2.    Keyword network analysis of depression after the COVID-19 pandemic.

TABLE III.    TOP 15 KEYWORDS BEFORE AND AFTER THE COVID-19 PANDEMIC

| Before the outbreak of COVID-19 pandemic | | | After the outbreak of COVID-19 pandemic | | |
|---|---|---|---|---|---|
| Word | Frequency | TF-IDF | Word | Frequency | TF-IDF |
| Depression | 17733 | 16660.1469 | Depression | 13753 | 17836.1839 |
| Seoul | 7169 | 13227.3619 | Covid-19 Pandemic | 12413 | 17370.7382 |
| USA | 5668 | 11789.2733 | Seoul | 7745 | 14491.2603 |
| Korea | 4852 | 10846.0941 | Corona Virus | 6872 | 13679.5616 |
| Depressive Syndrome | 2558 | 7355.18821 | USA | 6009 | 12767.9171 |
| Possibility | 2474 | 7196.23002 | Depressive Symptoms | 5345 | 11982.8225 |
| Victim | 2423 | 7098.33421 | Korea | 4313 | 10594.2729 |
| Japan | 2280 | 6818.0422 | Online | 3773 | 9772.40313 |
| Korea | 2245 | 6748.09391 | Police | 3189 | 8795.90881 |
| Person | 2133 | 6520.54938 | Victim | 3188 | 8794.15013 |
| Children | 2125 | 6504.07473 | Infectious Disease | 2745 | 7982.6753 |
| Police | 2125 | 6504.07473 | Select | 2518 | 7539.80287 |
| Myself | 1899 | 6025.77282 | Discovery | 2388 | 7277.06911 |
| Broadcast | 1798 | 5803.49877 | Possibility | 2225 | 6937.58891 |
| China | 1786 | 5776.71894 | Youtube | 2001 | 6451.3782 |
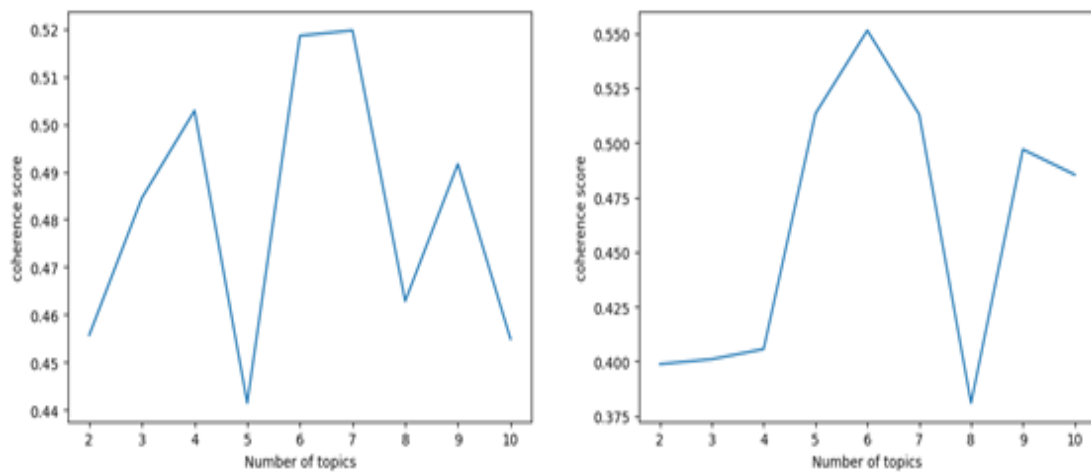


Fig. 3.    Consistency score before and after COVID-19 pandemic outbreak.

TABLE IV.    TOPIC MODELING BEFORE THE OUTBREAK OF COVID-19 PANDEMIC

| Group | Topic name | Top 5 words |
|---|---|---|
| 1 | Depression of celebrity | Depression, Person, Broadcasting, Depression, Self |
| 2 | Depression and crime | Depression, Victim, Seoul, Court, Lawyer |
| 3 | Depression and female crime | Depression, Police, Investigation, Charges, Woman |
| 4 | Depression around the world | USA, Depression, Korea, UK, China |
| 5 | Overcoming depression | Confidence, Things, Friends, Viewers, Tears. |
| 6 | Depression in the general public | Seoul, Depression, Children, Korea, Office workers |
| 7 | Symptoms and causes of depression | Depression, Depression, Insomnia, Health, Stress |

*2) LDA topic modeling:* In the LDA topic modeling results of this study, we have provided the top five words for each topic, as the weight of the 6th word in some topics was low. The results of topic modeling before the COVID-19 pandemic are presented in Table IV. The topics identified include famous individuals' confessions and overcoming depression, crime-related topics, global depression issues, and discussions on symptoms and causes of depression.

The results of the LDA topic modeling after the COVID-19 pandemic are presented in Table V. The differences between the topics before and after the COVID-19 pandemic can be observed, such as Topic 3 (COVID-19 pandemic and depression) and Topic 6 (depression and suicide), which specifically focus on the COVID-19 pandemic-related issues and suicide.

TABLE V.    TOPICS MODELING AFTER THE OUTBREAK OF THE COVID-19 PANDEMIC

| Group | Topic name | Top 5 words |
|---|---|---|
| 1 | Depression of celebrity | Depression, Agency, MBC (broadcasting), People, Fans |
| 2 | Covid-19 pandemic and depression around the world | United States, Depression, Korea, COVID-19 pandemic, Confirmed cases |
| 3 | Covid-19 pandemic and depressive symptoms | COVID-19 pandemic, Corona, Seoul, Depression, Coronavirus |
| 4 | Depression and crime | Depression, Seoul, Court, Victim, Defendant |
| 5 | Government and depression | Blue House, Immunity, Depression, Victims, Seoul |
| 6 | Depression and suicide | Police, Discovery, Selection, Investigation, Death |

## IV. DISCUSSION

In this study, we analyzed social issues related to depression before and after the COVID-19 pandemic using LDA topic modeling based on a large dataset of news articles (95,687 articles). We found that keywords related to "suicide" appeared prominently after the COVID-19 pandemic, unlike before the pandemic. The emergence of these keywords as potential key topics can be attributed to the prolonged duration of the COVID-19 pandemic, which has led to an increase in feelings of depression and suicidal ideation.

According to the Ministry of Health and Welfare, in 2020 when the initial wave of the COVID-19 pandemic occurred, there was a slight decrease in suicide deaths compared to 2019. This was attributed to factors such as a decrease in copycat suicides and social tension and cohesion resulting from a national disaster [15]. However, in 2021, both the number of suicide deaths and suicide rates increased by 1.2% compared to 2020 [16]. This suggests that with the prolonged duration of the COVID-19 pandemic, there has been an increase in feelings of depression and suicidal ideation [16], leading to an increase in youth suicide rates during the mid-term period of the COVID-19 pandemic [17].

The phenomenon of increasing youth suicide rates has also been reported overseas. In Japan, there was a 41.3% increase in youth suicides compared to 2019 [18], while overall adolescent suicides increased during the COVID-19 pandemic period in the United States [19]. Taking all these factors into account, it is speculated that there has been an increase in suicide deaths due to various social changes after the onset of the COVID-19 pandemic.

Another finding of this study is the discovery of topics related to the COVID-19 virus and depression after the onset of the COVID-19 pandemic. According to an online survey conducted by the Korea Health Promotion Institute targeting individuals aged 20 to 65, 40.7% of respondents reported experiencing "COVID-19 depression" [5]. In addition, a mobile survey conducted on individuals aged 15 and above in 17 metropolitan cities and provinces nationwide found that 47.8% of respondents reported experiencing depression and anxiety due to COVID-19 [20]. These survey results indicate

that due to the prolonged duration of the COVID-19 pandemic, a significant number of people have experienced varying degrees of depression. Therefore, it is necessary for the government to explore measures to monitor mental health among all citizens on a national level, and prepare strategies to reduce depression and anxiety in future outbreaks or pandemics.

Although this study examined social changes related to depression before and after the onset of the COVID-19 pandemic using news big data and employed LDA topic modeling to identify issues, it has several limitations. Firstly, the data used in this study does not include time-series information, so we cannot examine trends over time. Therefore, future research should consider incorporating time-series analysis to observe changes in trends. Secondly, the collected data is limited to domestic news articles, so generalization to other cultural contexts may not be possible. Thirdly, the topic names derived from LDA are researcher-inferred labels; therefore, future research should consider applying algorithms that can complement this process.

## V. CONCLUSION

In this study, we utilized BigKinds to analyze news articles related to depression before and after the onset of the COVID-19 pandemic using LDA topic modeling. We aimed to identify the main issues and differences between these periods. The results revealed that topics related to suicide emerged after the COVID-19 pandemic, as well as topics related to the COVID-19 virus and depression. Based on these findings, it is necessary for national-level policies to be developed in order to manage the mental health of citizens, such as depression, in future situations like infectious disease outbreaks.

## REFERENCES

[1] "2022 White paper on suicide prevention", Ministry of Health & Welfare, KOREA FOUNDATION FOR SUICIDE PREVENTION 2022.

[2] S. B. Hong, Restriction on SSRI (Selective Serotonin Reuptake Inhibitor) Antidepressant Prescription and Effort to Improve. Korean Journal of Family Practice, vol. 12, no. 4, pp. 212-216, 2022. doi: 10.21215/kjfp.2022.12.4.212.

[3] Gender general health examination mental health examination results by age by city and province, Statistics Korea, 2023. https://kosis.kr/statHtml/statHtml.do?orgId=350&tblId=DT_35007_N1180&conn_path=I2.

[4] Tackling the mental health impact of the COVID-19 crisis: An integrated, whole-of-society response, Organisation for Economic Co-operation and Development, 2021. https://www.oecd.org/coronavirus/policy-responses/tackling-the-mental-health-impact-of-the-covid-19-crisis-an-integrated-whole-of-society-response-0ccafa0b/

[5] 40.7% of Koreans said, "I experienced depression and anxiety due to COVID-19.", Korea Health Promotion Institute, 2020. https://www.khepi.or.kr/board/view?pageNum=6&rowCnt=10&no1=55

3&linkId=1001456&menuId=MENU00907&schType=0&schText=&boardStyle=&categoryId=&continent=&country=&contents1=

[6] E. J. Lee, and S. J. Kim, Prevalence and Related Factors of Depression Before and During the COVID-19 Pandemic: Findings From the Korea National Health and Nutrition Examination Survey. Journal of Korean Medical Science, vol. 38, no. 10, pp. e74, 2023. doi: 10.3346/jkms.2023.38.e74

[7] National Medical Center, completes debate on proposed medical response directions to prepare for COVID-19 resurgence, National Medical Center, 2022. https://www.nmc.or.kr/nmc/bbs/B0000008/view.do?nttId=14764&menuNo=200394&pageIndex=1

[8] T. P. Hong, C. W. Lin, K. T. Yang, and S. L. Wang, 2013). Using TF-IDF to hide sensitive itemsets. Applied Intelligence, vol. 38, pp. 502-510, 2013. doi: 10.1007/s10489-012-0377-5

[9] L. He, D. Han, X. Zhou, and Z. Qu, The voice of drug consumers: online textual review analysis using structural topic model. International Journal of Environmental Research and Public Health, vol. 17, no. 10, pp. 3648, 2020. doi: 10.3390/ijerph17103648

[10] K. Bastani, H. Namavari, and J. Shaffer, Latent Dirichlet allocation (LDA) for topic modeling of the CFPB consumer complaints. Expert Systems with Applications, vol. 127, pp. 256-271, 2019. doi: 10.1016/j.eswa.2019.03.001

[11] D. M. Blei, Probabilistic topic models. Communications of the ACM, vol. 55, no. 4, pp.77-84, 2012. doi: 10.1145/2133806.2133826

[12] Bigkinds. https://www.bigkinds.or.kr/

[13] B. H. Park: Okcheon-gun, Zero Depression Project Nationally Attended, Chungcheong Today, 2017. https://www.cctoday.co.kr/news/articleView.html?idxno=1106216

[14] S. H. Lee: 16% of Asan city officials 'at risk' of depression, asiatoday news, 2016. https://www.asiatoday.co.kr/view.php?key=2016082401001 2676

[15] 13,195 suicide deaths in 2020, down slightly from previous year, Ministry of Health & Welfare, 2021. https://www.mohw.go.kr/react/al/sal0301vw.jsp?PAR_MENU_ID=04&MENU_ID=0403&CONT_SEQ=368016&page=3

[16] 13,352 suicide deaths in 2021, up slightly from last year, Ministry of Health & Welfare, 2022. https://www.mohw.go.kr/react/al/sal0301vw.jsp?PAR_MENU_ID=04&MENU_ID=0403&page=2&CONT_SEQ=373035&SEARCHKEY=TITLE

[17] H. G. Woo et al., National Trends in Sadness, Suicidality, and COVID-19 Pandemic–Related Risk Factors Among South Korean Adolescents From 2005 to 2021. JAMA network open, vol. 6, no. 5, pp.e2314838-e2314838, 2023. doi: jamanetworkopen.2023.14838

[18] M. G. Kang, [Japan] COVID-19 and Suicide of Children and Youth. Changbi Children, vol. 19, no. 2, pp. 14-16, 2021.

[19] J. A. Bridge et al., Youth suicide during the first year of the COVID-19 pandemic. Pediatrics, vol. 151, no. 3, pp. e2022058375, 2023. doi: 10.1542/peds.2022-058375

[20] "Mental Health for the COVID-19 Generation!", Gyeonggi Research Institute, 2020.

# Construction of an Intelligent Robot Path Recognition System Supported by Deep Learning Network Algorithms

Jiong Chen*

Department of Artificial Intelligence, Shanxi Polytechnic College, Taiyuan, 030006, China

*Abstract*—In recent years, intelligent robots have been widely used in fields such as express transportation, industrial automation, and healthcare, bringing great convenience to people's lives. As one of the core technologies of intelligent robots, path planning technology has become a research highlight in the field of robotics. To achieve path planning in unknown environments, a path planning algorithm based on an improved dual depth Q-network is proposed. In both simple and complex grid environments, the planned path inflection points for the improved dual depth Q-network is 4 and 9, respectively, with path lengths of 27.21m and 28.63m, respectively. Both are less than double depth Q network and adaptive Ant colony optimization algorithms. The average reward values of the improved dual depth Q network in simple and complex environments are 1.12 and 1.02, respectively, which are higher than those of the dual depth Q network. In a random environment, the lowest probability of the improved dual depth Q network successfully reaching the destination without colliding with obstacles is 95.1%, which is higher than the other two algorithms. In the Gazebo environment, when the number of iterations reaches 2000, the average cumulative reward value is positive. The average cumulative reward value in the range of iterations from 3500 to 4000 and iterations from 4000 to 4500 exceeds 500. The average cumulative reward value of the dual depth Q network is only positive within the two intervals of iterations 2500-3000 and 3000-3500. The average cumulative reward value does not exceed 100. According to the findings, the path planning ability of the improved dual depth Q network is better than that of the dual depth Q network and the adaptive Ant colony optimization algorithms.

*Keywords—Deep learning; reinforcement learning; intelligent robots; path planning*

## I. INTRODUCTION

With the progress of computer technology, intelligent robots have gradually entered people's lives. They play an important role in their respective fields. At the same time, due to the technological reform of intelligent robots, humans have gradually raised their requirements for the mobility of intelligent robots. Intelligent robots are expected to quickly plan a route to the destination in unfamiliar environments. The path planning of robots consists of global path planning and local path planning based on their mastery of environmental information. In local path planning, the motion trajectory of the robot has uncertainty. It needs to constantly obtain information from the environment to determine the next step. At the same time, it is necessary to obtain data information on obstacles to

avoid unknown obstacles [1]. Reinforcement learning (RL) is a good solution to how to avoid unknown obstacles. However, in a complex environment, RL will have an exponential growth problem of state-action collection, resulting in a "Curse of dimensionality" [2]. The deep reinforcement learning (DRL) obtained from deep learning (DL) combined with Reinforcement learning can effectively improve the above problems. The deep learning in Deep reinforcement learning can extract the data information characteristics of the environment through neural network, realizing the fitting between the state-action value function (SAVF) and the environment [3]. At present, DRL has become a popular algorithm in the research of robot path planning (RPP) for unknown environments. However, due to the overestimation of DL, the output state-action values in DRL applications are higher than the true values. Therefore, to realize the path planning of the robot in an unknown environment, the influence of overestimation on the robot action selection is reduced. A RPP based on Improved Double Deep Q-Network (IDDQN) is proposed in the research. This algorithm effectively avoids the "dimension disaster" problem, ensures the action speed and accuracy of the robot, enriches the application scenarios of the robot, and provides strong support for the future intelligence of the robot.

The article consists of four sections. Section I is the introduction. Section II deals with related works. Section III deals with RPP algorithm based on DRL. Section IV is the simulation experiments and result analysis and Section V concluded the whole study.

## II. RELATED WORKS

In the current research on various technologies of intelligent robots, path planning is a hot research direction. The way and quality of path planning determine whether a robot can safely and quickly reach the destination. Rath A K and his team proposed a navigation control algorithm based on genetic algorithm (GA) and neural network for robot navigation problems in complex environments. The GA controller is used to generate the initial turning angle of the robot. Then, the GA controller and neural network controller are mixed to generate the final steering angle. After testing, the navigation parameter error of this algorithm is relatively small [4]. Nie B et al. proposed a path planning method based on value iteration for intelligent agents with complex kinematics. The state-action transition probability is used to encode the ability of the agent. According to the findings, it has higher precision, faster

convergence rate and lower random seed sensitivity [5]. Wang G and other scholars proposed a dynamic path planning method based on fuzzy neural networks for intelligent robots. Compared with the traditional Particle swarm optimization (PSO), it can significantly improve the control accuracy and robustness of the model [6]. Oultiligh A and his team proposed a trajectory planning method based on PSO and gray wolf optimization for mobile robot trajectory optimization. This algorithm can effectively balance global and local search capabilities. After testing, the optimal trajectory search ability of PSO-GWO has significantly improved [7]. Raheem F A et al. proposed a RPP method based on probabilistic landmarks and artificial potential fields. The PSO is applied to obtain the optimization weight required by each control point participating in the formation of the spline curve. After testing, this method can ensure the feasibility and rationality of the path [8].

As an artificial intelligence method close to human thinking mode, DRL is an effective way to solve complex perception problems. Therefore, it is widely used in automatic driving, robotics, game control, machine translation and other fields. Guang zheng W et al. proposed a DRL based collision detection and avoidance method for distributed multiple unmanned aerial vehicles. Human experience is also integrated into training. Compared to traditional DRL methods, DRL that integrates human experience has significant improvements in multi drone collision detection and avoidance. In addition, the flight safety brought by the hybrid control method has also been verified [9]. Cao D and his team proposed an analysis method based on MDP and PPO to analyze the optimal power flow problem of distribution networks containing renewable energy and energy storage devices. This method obtains knowledge from historical data through neural networks and provides online decision-making based on the real-time status of the power grid. The experimental results show that the real-time control strategy proposed by this method is more flexible, which has better performance [10]. Zhao J et al. proposed a dynamic multi micro grid formation method based on CNN and DDQN to develop a multi micro grid formation plan. In this method, the dynamic micro grid formation problem is transformed into a Markov decision process. The topology changeable micro grid is designed through the DRL framework. According to the findings, this method has strong elasticity, which can respond to changing system conditions in a timely manner [11]. Zhang D et al. proposed a two-stage deep Q-learning algorithm based on pre-exploration for intelligent train control. After testing, this algorithm smoothes the acceleration curve. It can effectively complete train control tasks in multi train tracking scenarios [12]. Shihab S A M and Wei P proposed a strategy formulation method based on DRL for developing optimal seat inventory control strategies. In this method, DNN is used to calculate the expected optimal return for all possible state action combinations. Various factors such as random demand, passenger arrival, and booking cancellation have been fully considered. According to the findings, interacting with the market can learn the optimal airline revenue management strategy [13].

In summary, with the development of intelligent robot technology, RPP methods for mobile robots have become a hot

research topic. There have been significant achievements in current research on RPP. In local path planning, DRL is a popular algorithm. However, due to the inherent overestimation problem of RL, the path chosen by the robot is not necessarily the optimal path. To address the above issues, a RPP method based on IDDQN is proposed, aiming to achieve local path planning in unfamiliar environments.

## III. RPP ALGORITHM BASED ON DRL

With the progress of science and technology, robot technology is receiving increasing attention from people. As one of the core technologies of intelligent mobile robots, path planning has become a research highlight in the robotics. To achieve safe movement of robots in unknown environments, a RPP method based on improved DDQN is proposed-IDDQN. The IDDQN algorithm effectively avoids the DDQN over estimation through more moderate Q update method and improves the utilization efficiency through the sequencing of priority playback mechanism. It effectively reduces the disadvantage of slow DDQN training speed.

### A. RPP based on DDQN

The core of DRL is Reinforcement learning. Reinforcement learning guides behavior through rewards gained from interaction with the environment. However, the reinforcement learning model is more complex. Therefore, MDP is introduced into the reinforcement learning model to simplify it. In RPP, the probability of state transition and the immediate reward return function are generally unknown. Therefore, robots need to constantly interact with the environment. The state transition probability reflecting actions is displayed in Eq. (1).

$$P_{ss'}^a = P\left[ S_{t+1} = s' \middle| S_t = s, A_t = a \right] \quad (1)$$

In Eq. (1), $P_{ss'}^a$ represents the execution of action $a$ in state $s$. $s'$ represents the probability that the robot can reach the state. $P$ represents the probability of state transition. $S_t$ represents the set of state spaces at time $t$. $A_t$ stands for the set of action spaces at time $t$. The calculation method for cumulative reward value (CRV) is shown in Eq. (2).

$$G_t = R_{t+1} + \gamma R_{t+2} + L = \sum_{k=0}^{\infty} \gamma^k R_{t+k+1} \quad (2)$$

In Eq. (2), $R$ represents the immediate reward function. $\gamma$ represents the discount factor. $G_t$ represents the CRV. The state VF is shown in Eq. (3)

$$v_\pi(s) = E_\pi\left[ \sum_{k=0}^{\infty} \gamma^k R_{t+k+1} \middle| S_t = s \right] \quad (3)$$

In Eq. (3), $v_\pi(s)$ represents the state value function (SVF). $\pi$ stands for strategy. $E_\pi$ represents the expected cumulative reward return in strategy $\pi$. The SAVF is shown in Eq. (4).

$$q_\pi(s,a) = E_\pi\left[\sum_{k=0}^{\infty}\gamma^k R_{t+k+1}\,\middle|\,S_t = s, A_t = a\right] \tag{4}$$

In Eq. (4), $q_\pi(s,a)$ represents the action SVF. The calculation of the SVF is to construct the data in the algorithm to obtain the optimal strategy. The Bellman optimal equations for the SVF and the SAVF are shown in Eq. (5).

$$\begin{cases} v^*(s) = \max_a R_s^a + \gamma\sum_{s'\in S}P_{ss'}^a v^*(s') \\ q^*(s,a) = R_s^a + \gamma\sum_{s'\in S}P_{ss'}^a \max_{a'} q(s',a') \end{cases} \tag{5}$$

In Eq. (5), $v^*(s)$ and $q^*(s,a)$ represent the optimal SVF and the optimal SAVF, respectively. If the optimal SVAF is already specified, the optimal strategy is determined by maximizing the optimal SVAF. At this point, the optimal strategy expression is shown in Eq. (6).

$$\pi^* = \begin{cases} 1 & a = \arg\max_{a\in A} q^*(s,a) \\ 0 & otherwise \end{cases} \tag{6}$$

Eq. (6) indicates that the SVAF is the maximum. At this point, under strategy $\pi$ and state $s$, the probability of the robot executing action $a$ is 1. The execution probability of other actions is 0. The value function of the DQN algorithm utilizes DNN for approximation. The network structure of DQN is illustrated in Fig. 1.

In Fig. 1, the parameters corresponding to the DQN value function represent the weight size of each layer in DNN. At

this point, updating the value function means updating the network parameters. If the network structure is determined, the network parameters are the value function [14-15]. When using DNN to approximate a value function, the strong correlation between data sample tuples can easily lead to instability and non-convergence issues. Therefore, experience playback technology is used to address this issue. The experience of each time step is stored in the data pool. When updating network parameters, random samples are taken from the data pool for training. The method for updating network parameters is shown in Eq. (7).

$$\theta_{t+1} = \theta_t + \alpha\left[\begin{matrix}r + \gamma\max_a Q(s',a',\theta) \\ -Q(s,a,\theta)\end{matrix}\right]\nabla Q(s,a,\theta) \tag{7}$$

In Eq. (7), $\theta$ represents the network parameters. $Q(s,a,\theta)$ represents the value function of Q-Learning. $\alpha$ represents a parameter. $r$ represents timely return. However, when calculating the SAVF, the parameters used are the same as those approximated by the value function, which can easily lead to unstable training. Calculating the time difference optimization objective through target network parameters can effectively solve this problem. At this point, the parameter update formula is shown in Eq. (8).

$$\theta_{t+1} = \theta_t + \alpha\left[\begin{matrix}r + \gamma\max_{a'} Q(s',a',\theta^-) \\ -Q(s,a,\theta)\end{matrix}\right]\nabla Q(s,a,\theta) \tag{8}$$

In Eq. (8), $\theta^-$ stands for the parameters of the target network. The training process of DQN is shown in Fig. 2.
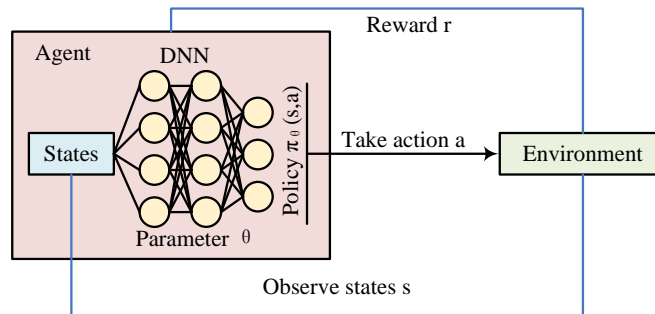


Fig. 1. Network structure of DQN.
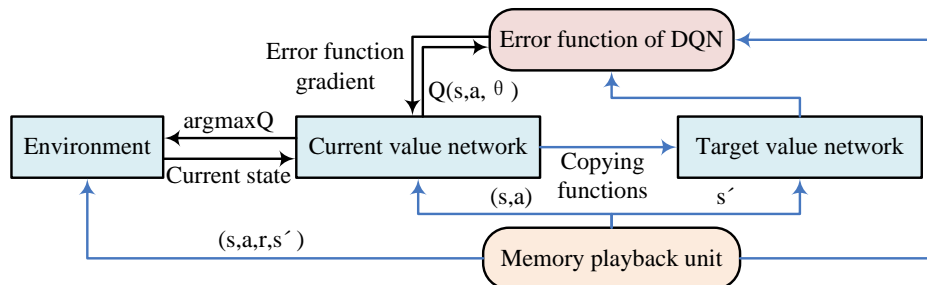


Fig. 2. Training process of DQN.

In Fig. 2, for each step reached, the parameters of the current value network are assigned to the target value network. In the playback memory unit, several samples are selected and their states are fed into the current value network. In the network output results, the Q value corresponding to the sample action is extracted and the target value is calculated. The loss function of Q value and target value is calculated. The current value network is updated by back-propagation. Although the DQN algorithm uses DNN instead of Q-table to approximate the SAVF, it still has overestimation issues [16-18]. The selection and evaluation of actions in network parameter updates are separated. Different value function networks are used to express action selection and evaluation. This can alleviate the problem, which is known as the DDQN algorithm. At this point, the calculation of the time difference optimization objective is shown in Eq. (9).

$$Y_t^{DDQN} = r + \gamma Q\left(s', \arg\max Q\left(s', a', \theta\right), \theta^-\right) \quad (9)$$

In Eq. (9), $Y_t^{DDQN}$ represents the optimization objective. $\theta$ and $\theta^-$ represent estimated network parameters and target network parameters, respectively.

### B. RPP based on Improved DDQN

In DDQN, the overestimation problem has a negative impact on the selection of the optimal action for robots, making it difficult to find the optimal action strategy and path. At the same time, as the interaction between robots and the environment deepens, the playback proportion of important samples decreases when playing back experience samples, resulting in the decline of robot learning effect. To address the above issues, an improved DDQN for RPP is proposed. The RPP training model is illustrated in Fig. 3.

From Fig. 3, the sample data is fed into the memory cache unit based on the current environment, the next state, and the obtained instant returns. Then, samples are selected from memory buffer units to train the parameters of the IDDQN. Then, based on the network output and improved exploration strategy, the optimal action is selected. The robot is sent to the next state [19-20]. In DDQN, there is a situation where the absolute error values of the value functions of the optimal and suboptimal actions are equal, resulting in the robot selecting a suboptimal action. To avoid the above issues, the range of error values can be reduced. To minimize the error, the ε-Greedy

strategy is introduced into DDQN. The improved optimization objective is shown in Eq. (10).

$$Y_t^{IDDQN} =$$
$$\begin{cases} r + \gamma Q\left(s', \arg\max Q\left(s', a', \theta\right), \theta^-\right) & \text{Probability} = 1 - \varepsilon' \\ r + \gamma Q\left(s', a', \theta^-\right) & \text{Probability} = \varepsilon' \end{cases} \quad (10)$$

In Eq. (10), $\varepsilon'$ represents a parameter, which is a fixed value, with a value range of $(0,1)$. $a'$ represents a random action. To better select actions, a ε-Greedy action selection strategy based on prior knowledge is proposed. The probability of action selection for strategy ε-Greedy is shown in Eq. (11).

$$\pi(a|s) = \begin{cases} 1 - \varepsilon + \dfrac{\varepsilon}{|A(s)|} & a = \arg\max_a Q(s,a) \\ \dfrac{\varepsilon}{|A(s)|} & a \neq \arg\max_a Q(s,a) \end{cases} \quad (11)$$

In Eq. (11), $A(s)$ represents the set of actions in state $s$. $\varepsilon$ represents the exploration factor. When the robot selects actions, a random number is generated. If the random number is less than the exploration factor, the robot randomly selects actions. Otherwise, the average Q value of previous generations will be calculated. Based on improved ε-Greedy strategy, corresponding actions are selected and executed. The average Q value is calculated as Eq. (12).

$$Q^A(s,a) = \frac{1}{K} \sum_{k=1}^{K} Q(s,a,\theta_{t-k}) \quad (12)$$

In Eq. (12), $K$ represents the algebraic difference between the current parameter and the previous parameter. $Q^A(s,a)$ represents the average Q value of the previous $K$-generations. In model training, the playback frequency of experience fragments with low time difference error values is low due to the influence of environmental noise. The lack of diversity in training samples leads to over fitting issues. Combining greedy finite and uniform sampling can ensure the playback probability of experience fragments with low time difference error values. The calculation formula for playback probability is shown in Eq. (13).
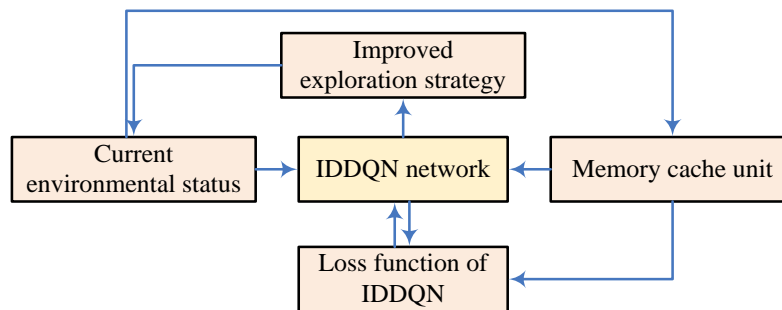


Fig. 3. Training model for robot path planning.

$$P_i = \frac{p_i^\alpha}{\sum_k p_k^\alpha} \qquad (13)$$

In Eq. (13), $P(i)$ represents the playback probability of the $i$-th segment. $p_i$ represents the priority of the $i$-th segment. $\alpha$ represents the degree of control priority. The priority calculation formula is shown in Eq. (14).

$$p_i = 1/rank_i \qquad (14)$$

In Eq. (14), $rank_i$ represents the sequence number sorted by the absolute value of time difference error. To prevent over fitting and ensure the diversity of experience fragments, weight is introduced for adjustment. The weight calculation formula is shown in Eq. (15).

$$w_i = 1 \Big/ \left( \frac{p_i}{p_{min}} \right)^\beta \qquad (15)$$

In Eq. (15), $p_{min}$ represents the minimum probability of the experience segment. $\beta$ represents the correction degree. At this time, the expression of loss function is shown in Eq. (16).

$$L = \sum w(t) \left( Y_t^{IDDQN} - Q(s,a,\theta) \right)^2 \qquad (16)$$

In Eq. (16), $Q(s,a,\theta)$ stands for the output Q of the estimated network. The IDDQN algorithm process is shown in Fig. 4.

From Fig. 4, the IDDQN algorithm first initializes the estimated network parameters, target network parameters, and experience playback pool. The event is cycled. Then the state of each cycle is initialized and cycled throughout the time cycle. Actions are randomly selected based on probability. If a small probability event does not occur, the action with the highest current value function is selected and executed. Next, based on the reward feedback of the environment and the transferred state, the time difference error value is calculated. The calculation results are arranged in order of size. According to the sequence number, priority is calculated. Based on priority, the sampling probability is obtained. Then the correction weight is calculated by sampling probability, and the experience fragments are put into the experience playback pool according to the probability. Next, samples are selected based on probability from the experience replay pool and optimization objectives are calculated. Then, the estimated parameters are updated according to the calculation results of the loss function. The target parameters are replaced by these parameters. The application process of IDDQN algorithm in robot path planning is shown in Fig. 5.
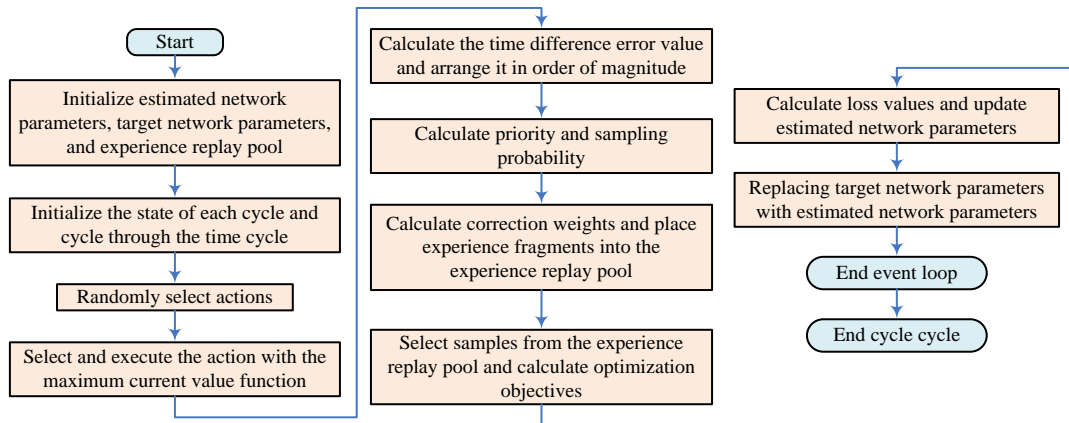
Fig. 4.   Flow of IDDQN algorithm.
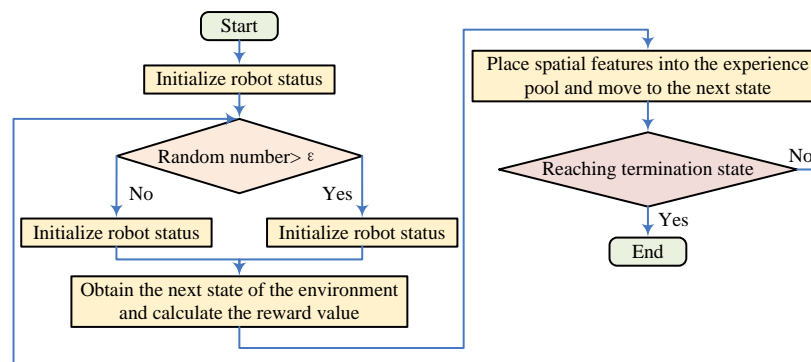
Fig. 5.   Application process of IDDQN in RPP.

In Fig. 5, this algorithm first initializes the state of the robot. The current coordinates of the robot are determined. Then the generated random numbers are compared. If it is greater than the exploration factor, the average output value of the improved optimization objective network is calculated and an action is selected. Otherwise, the action is randomly selected. Then the next state of the environment is obtained and its reward value is calculated. Then the spatial features are placed in the experience pool and moved to the next state. Finally, the current state is judged. If the termination state is reached, the process ends. Otherwise, the operation is returned to the second step.

## IV. Simulation Experiments and Result Analysis Based on Grid Environment and Gazebo Environment

To verify the path planning ability of the IDDQN, testing experiments are carried out in both grid and Gazebo environments. The proposed method is compared with DDQN algorithm and adaptive Ant colony optimization algorithms. The grid environment is divided into simple environment, complex environment, and random environment. The processor used in this simulation experiment is Xeon (R), the CPU is NVIDIA GeForce GTX 1080Ti, the running memory is 32 GB, and the software environment is Python and TensorFlow. The exploration factor for grid and Gazebo environments has an initial value of 1 and an end value of 0.1. The convergence of

DDQN, adaptive ant colony algorithm, and IDDQN algorithm is shown in Fig. 6.

From Fig. 6, the DDQN value converges after approximately 270 iterations, with a loss value of approximately 0.24. The adaptive Ant colony optimization algorithm starts to converge after about 220 iterations, and the loss value is about 0.21. IDDQN begins to converge after approximately 180 iterations, with a loss value of approximately 0.19. The convergence rate of IDDQN is faster. The RPP results of the three methods in a simple environment are shown in Fig. 7.
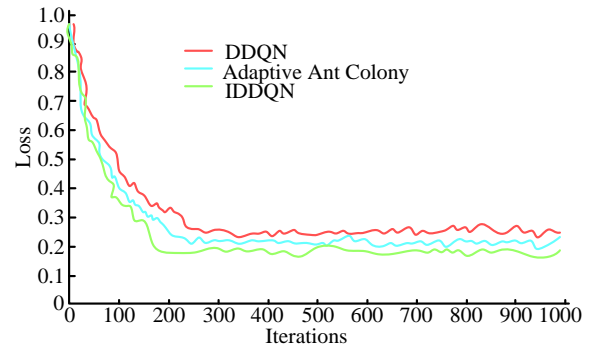


Fig. 6. Convergence of DDQN, adaptive ant colony, and IDDQN.



(a)DDQN Planning Path



(b)Adaptive Ant Colony Planning Path



(c)IDDQN Planning Path
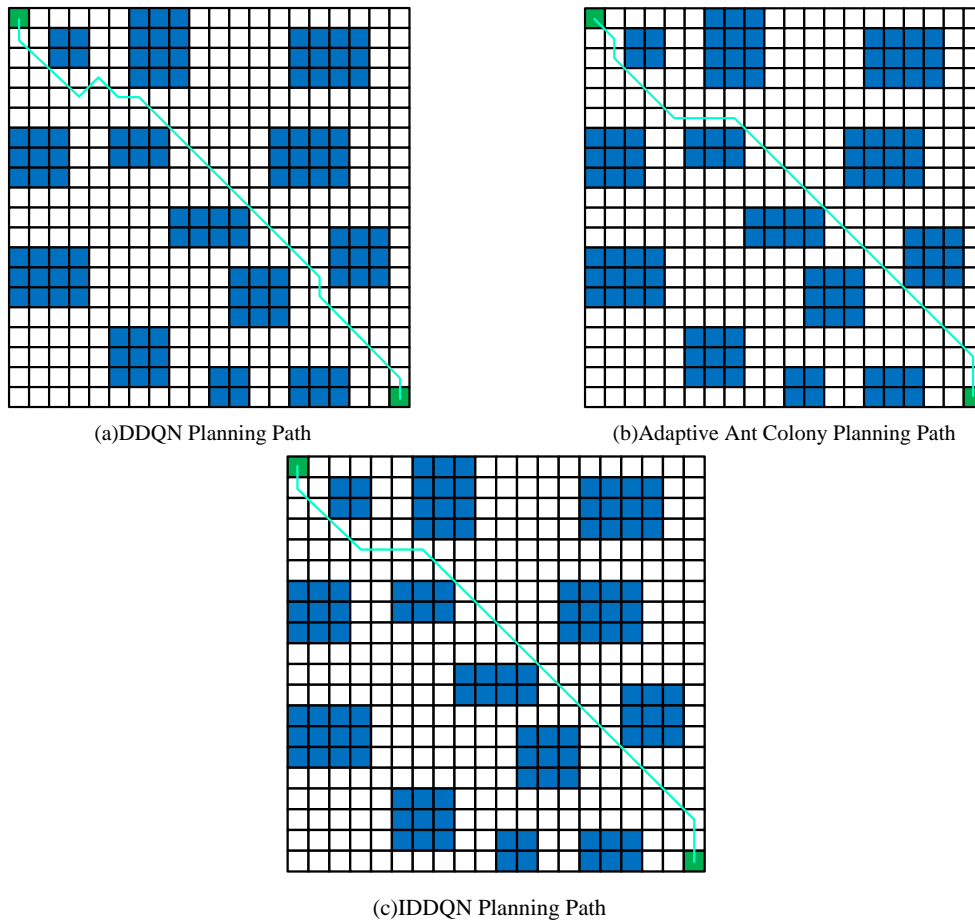
Fig. 7. RPP results of three methods in a simple environment.
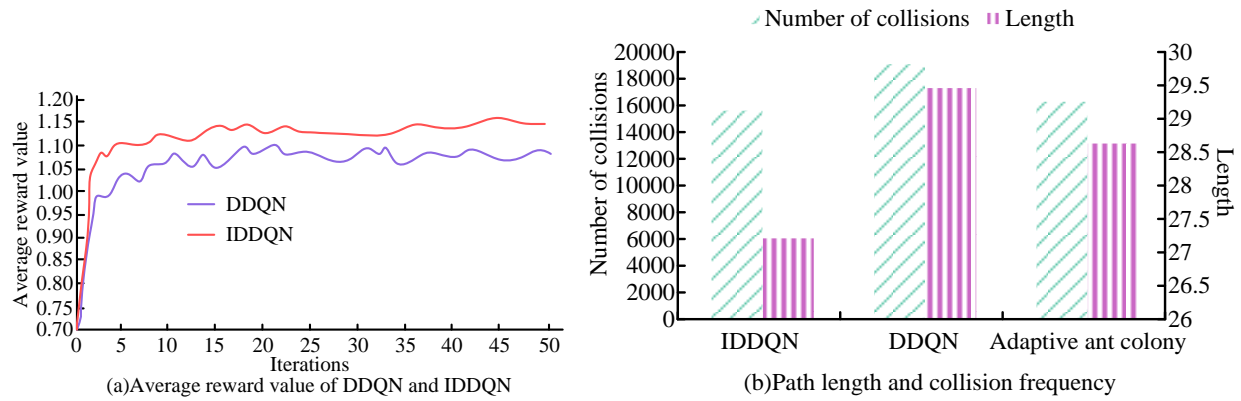
Fig. 8. The average reward values of IDDQN and DDQN, as well as the path length and collision frequency of the three algorithms.

From Fig. 7 (a), the path inflection points planned for DDQN are 8. In Fig. 7(b), the path inflection points planned by the adaptive Ant colony optimization algorithms are 5. In Fig. 7(c), the inflection points in the planned path of IDDQN are 4. IDDQN has fewer inflection points in the planned path, which can effectively reduce the movement time from the starting to the target position. The average reward values of IDDQN and DDQN, as well as the path lengths and collision times of the three algorithms, are shown in Fig. 8.

In Fig. 8(a), the average reward value of DDQN is approximately 1.03. IDDQN has an average reward value of approximately 1.12, which is higher than the DDQN algorithm. In Fig. 8(b), the path length planned by the DDQN is approximately 29.46m, and the number of obstacle collisions is 19806. The optimal path length of the adaptive Ant colony optimization algorithms is about 28.63m, and the collisions with obstacles are 16275. The optimal path length for IDDQN planning is approximately 27.21m, and the number of collisions with obstacles during training is 15613. The IDDQN algorithm not only has the shortest planned path length, but also reduces the probability of robot collision with obstacles. The RPP results of the three methods in complex environments are illustrated in Fig. 9.

In Fig. 9(a), the inflection points planned by the DDQN algorithm are 10, the inflection points of the path planned by the adaptive Ant colony optimization algorithms are 13. The path inflection points planned by IDDQN are 9. From Fig. 9(b), in complex environment 2, the path inflection points of both the ant colony algorithm and DDQN are redundant with IDDQN. The length is also longer than the IDDQN algorithm. From this, in complex environments, the IDDQN algorithm can still move to the endpoint with as few inflection points as possible. In a complex environment, the path lengths and collision times of the three algorithms, as well as the reward values of IDDQN and DDQN, are shown in Fig. 10.

From Fig. 10(a), the optimal path length for DDQN planning is approximately 29.22 m, and the number of collisions during training is 26671. The optimal path length for the adaptive Ant colony optimization algorithms is about 29.80 m, and the number of collisions is 19374. The optimal path length for IDDQN is approximately 28.63m and the number of collisions is 17389. In Fig. 10(b), the average reward values for DDQN and IDDQN are approximately 0.92 and 1.02, respectively. The average reward value of IDDQN is higher. IDDQN can still maintain a small collision probability in complex environments. The success rates and path length differences of the three algorithms in a random environment are shown in Fig. 11.



(a) Complex Environment 1



(b) Complex Environment 2
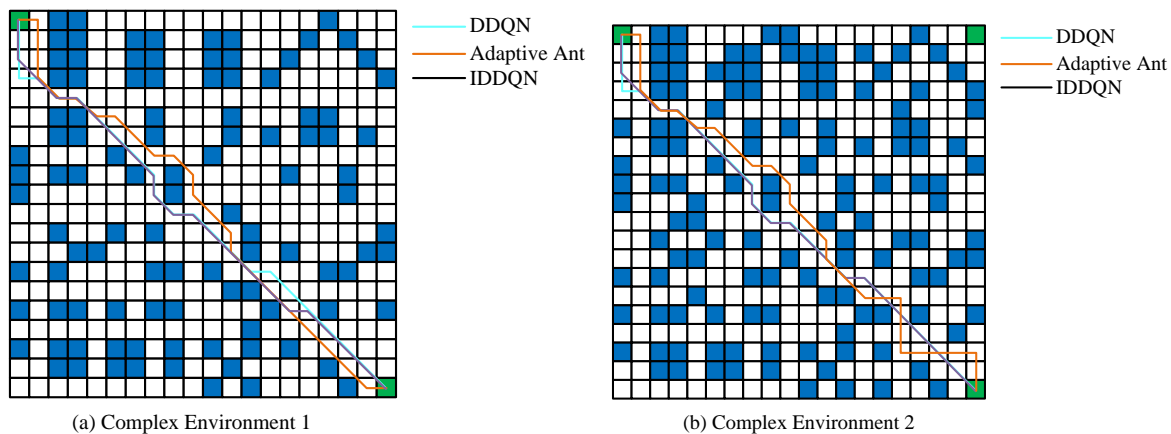
Fig. 9. RPP results in complex environments.

(a)Path length and collision frequency



(b)Average reward value of DDQN and IDDQN
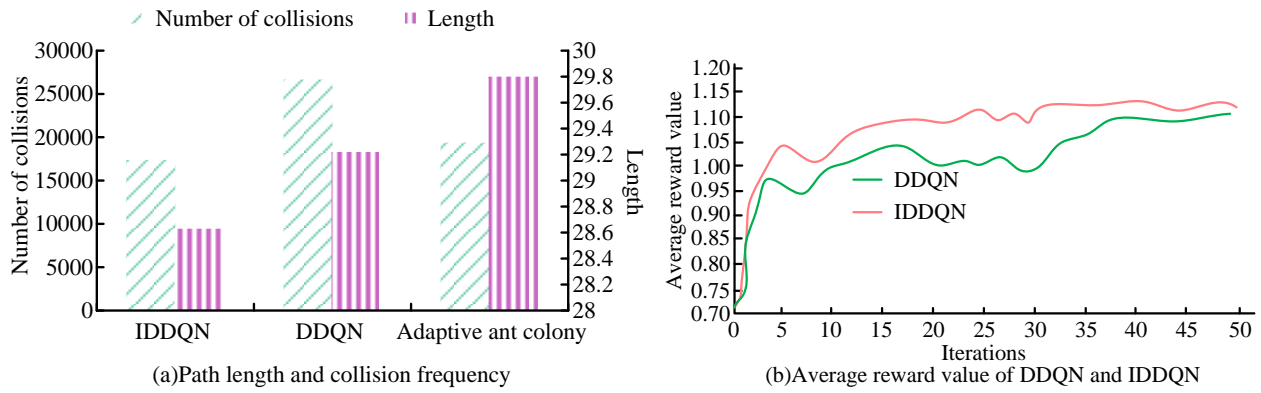
Fig. 10. The path length, collision frequency, and reward values for IDDQN and DDQN of the three algorithms are shown in the figure.



(a) Success rate



(b) Path length difference
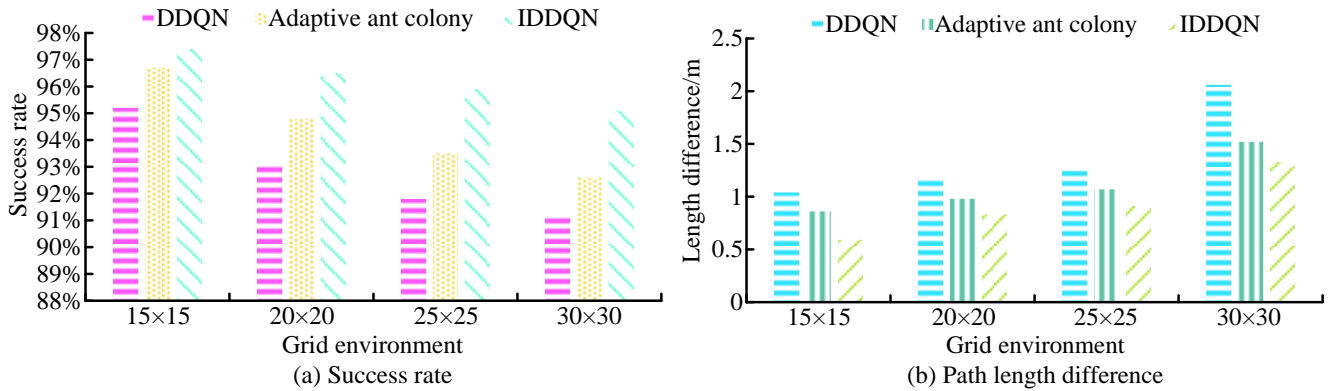
Fig. 11. Success rates and path length differences of three algorithms in a random environment.
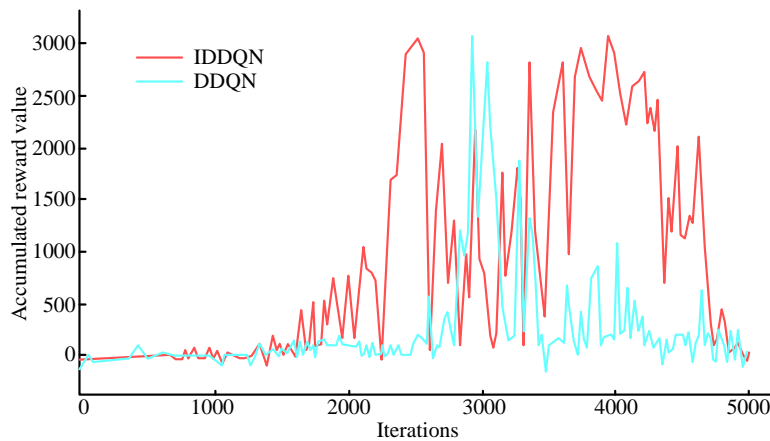


Fig. 12. Accumulated reward values of DDQN and IDDQN.

In Fig. 11 (a), in a random environment, the probability of DDQN successfully reaching the destination without colliding with obstacles is approximately 95.2%, 93.1%, 91.8%, and 91.2%, respectively. The success rate of adaptive Ant colony optimization algorithms in random environment is about 96.7%, 94.8%, 93.5% and 92.6% respectively. The success rates of IDDQN in random environments are approximately 97.4%, 96.5%, 95.9%, and 95.1%, respectively. IDDQN has the highest success rate in a random environment. In Fig. 11(b), the path length difference of DDQN in different environments is about 1.04 m, 1.17 m, 1.25 m, and 2.06 m, respectively. The path length difference of the adaptive Ant

colony optimization algorithms is about 0.86 m, 0.98 m, 1.07 m and 1.52 m respectively. The difference in path length for IDDQN is approximately 0.59 m, 0.83m, 0.91m, and 1.33m, respectively. The path length difference of IDDQN is the smallest, indicating that IDDQN has a stronger ability to plan the optimal path. The CRVs of DDQN and IDDQN in the Gazebo environment are shown in Fig. 12.

In Fig. 12, the CRV of IDDQN is significantly higher than that of DDQN. The average CRV of DDQN is the highest in the range of 2500 to 3000 iterations. At this point, the average CRV is approximately 76.12. Secondly, there is an interval of

3000 to 3500 iterations, with an average CRV of approximately 29.83. The above two intervals are also the only ones with a positive average CRV. The average CRV of IDDQN is highest in the range of 3500 to 4000 iterations. The average CRV is around 748.62. Next is the interval of 4000 to 4500 iterations, with an average CRV of approximately 584.46. When the number of iterations reaches 2000, the average CRV is all positive. The average CRV between the iterations of 2000-2500 and 3000-3500 exceeds 100.

## V. CONCLUSION

A RPP algorithm based on the improved DDQN - IDDQN algorithm is proposed for the mobile RPP problem of intelligent robots in unknown environments. Simulation experiments are conducted in both grid and Gazebo environments. According to the results, IDDQN begins to converge after approximately 180 iterations. The loss value is approximately 0.19. The convergence rate is faster than DDQN algorithm and adaptive Ant colony optimization algorithms. In a simple grid environment, the optimal path length, inflection points, and collisions during training for IDDQN are 27.21m, 4, and 15613, respectively. In a complex grid environment, the optimal path length, number of inflection points, and number of collisions during training planned by the IDDQN algorithm are 28.63m, 9, and 17389, respectively. In a random environment, the path length differences of IDDQN are 0.59m, 0.83m, 0.91m, and 1.33m, respectively. It is less than the path planned by DDQN and adaptive Ant colony optimization algorithms. The success rates of the IDDQN algorithm in random environments are approximately 97.4%, 96.5%, 95.9%, and 95.1%, respectively, which are higher than other algorithms. In the Gazebo environment, the interval with the highest average cumulative reward value for DDQN is between 2500 and 3000 iterations. At this point, the average cumulative reward value is about 76.12, and there are only two intervals where the average cumulative reward value is positive. The average cumulative reward value of DDQN is the highest in the range of 3500 to 4000 iterations. The average cumulative reward value is around 748.62. When the number of iterations reaches 2000, the average CRV is all positive. The average CRV of two intervals exceeds 100. The above results indicate that the intelligent RPP based on IDDQN can achieve optimal RPP in unfamiliar environments. Research has achieved static path planning for robots by improving DDQN. However, the proposed method does not take into account the dynamic variable environment. At the same time, when several robots cooperate to complete a certain work, the proposed algorithm cannot provide reasonable task assignment and collaboration instructions for the robot. Therefore, future work will focus on path planning, multi-robot collaborative task assignment, and path planning in dynamically variable environments.

## ACKNOWLEDGMENT

## REFERENCES

[1] J. Zan. "Research on robot path perception and optimization technology based on whale optimization algorithm," J. Comput. Cognitive Eng., vol. 1, no. 4 pp. 201-208, Aug. 2022.

[2] G. Campos, N. H. El-Farra, and A. Palazoglu, "Soft actor-critic deep reinforcement learning with hybrid mixed-integer actions for demand responsive scheduling of energy systems," Ind. Eng. Chem. Res., vol. 61, no. 24, pp. 8443-8461, Apr. 2022.

[3] Y. Yang and. X. Song, "Research on face intelligent perception technology integrating deep learning under different illumination intensities," J. Comput. Cognitive Eng., vol. 1, no. 1, pp. 32-36, Aug. 2022.

[4] A. K. Rath, D. R. Parhi, H. C. Das, P. B. Kumar, and M. K. Mahto, "Design of a hybrid controller using genetic algorithm and neural network for path planning of a humanoid robot," Int. J. Intell. Unmanned Syst.,vol. 9, no. 3, pp. 169-177, May. 2021.

[5] B. Nie, Y. Gao, Y. Mei, and F. Gao, "Capability iteration network for robot path planning," Int. J. Robotics Automation, vol. 37, no. 3, pp. 266-272, Apr. 2022.

[6] G. Wang and J. Zhou, "Dynamic robot path planning system using neural network," J. Intell. Fuzzy Syst., vol. 40, no. 2, pp. 3055-3063, Feb. 2021.

[7] A. Oultiligh, H. Ayad, A. E. Kari, M. Mjahed, and N. E. L. Gmili, "A hybrid PSO-GWO algorithm for robot path planning in uncertain environments," Int. Rev. Automat. Contr., vol. 14, no, 6, pp. 360-372, Aug. 2021.

[8] F. A. Raheem and M. I. Abdulkareem, "Development of A* algorithm for robot path planning based on modified probabilistic roadmap and artificial potential field," J. Eng. Sci. Technol., vol. 15, no. 5, pp. 3034-3054, Oct. 2020.

[9] W. Guanzheng, X. Yinbo, L. Zhihong, X. Xin, W. Xiangke, and Y. Jiarun, "Integrating human experience in deep reinforcement learning for multi-UAV collision detection and avoidance," Ind. Robot, vol. 49, no. 2, pp. 256-270, Sept. 2022.

[10] D. Cao, W. Hu, X. Xu, Q. Wu, Q. Huang, Chen Z., and F. Blaabjerg, "Deep reinforcement learning based approach for optimal power flow of distribution networks embedded with renewable energy and storage devices," J. Mod. Pow. Syst. Clean Energy, vol. 9, no. 5, pp. 1101-1110, Jun. 2021.

[11] J. Zhao, F. Li, S. Mukherjee, and D. Sticht, "Deep reinforcement learning based model-free on-line dynamic multi-microgrid formation to enhance resilience," IEEE Trans. Smart Grid, vol. 13, no. 4, pp. 2557-2567, Jul. 2022.

[12] D. Zhang, J. Zhao, Y. Zhang, and Q. Zhang, "Intelligent train control for cooperative train formation: A deep reinforcement learning approach," Proc. Inst. Mech. Eng., Part I: J. Syst. Contr. Eng., vol. 236, no. 5, pp. 975-988, Dec. 2022.

[13] S. A. M. Shihab and P. Wei, "A deep reinforcement learning approach to seat inventory control for airline revenue management," J. Revenue Pricing Manage., vol. 21, no. 2, pp. 183-199, Mar. 2022.

[14] Y. Zheng, J. Tao, Q. Sun, H. Sun, M. Sun, and Z. Chen, "An intelligent course keeping active disturbance rejection controller based on double deep Q-network for towing system of unpowered cylindrical drilling platform," Int. J. Robust and Nonlinear Contr., vol. 31, no. 17, pp. 8463-8480, Aug. 2021.

[15] Y. Dai, K. D. Lee, and S. G. Lee, "A real-time HIL control system on rotary inverted pendulum hardware platform based on double deep Q-network," Measure. Contr., vol. 54, no. 3-4, pp. 417-428, Mar. 2021.

[16] X. Tao and A. S. Hafid, "Deep sensing: a novel mobile crowd sensing framework with double deep Q-network and prioritized experience replay," IEEE Internet Things J., vol. 7, no. 12, pp. 11547-11558, Sept. 2020.

[17] Q. Fang, X. Xu, and D. Tang, "Loss-based active learning via double-branch deep network," Int. J. Advan. Robotic Syst., vol. 18, no. 5, pp. 538-550, Sept. 2021.

[18] J. Zhao, T. Qu, and F. Xu, "A deep reinforcement learning approach for autonomous highway driving," IFAC-PapersOnLine, vol. 53, no. 5, pp. 542-546, May. 2020.

[19] L. Xu, M. Cao, and B. Song, "A new approach to smooth path planning of mobile robot based on quartic Bezier transition curve and improved PSO algorithm," Neurocomputing, vol. 473, no. 7, pp. 98-106, Feb. 2022.

[20] Y. Yang, Z. Lin, M. Yue, G. Chen, and J. Sun, "Path planning of mobile robot with PSO-based APF and fuzzy-based DWA subject to moving obstacles," Trans. Inst. Measure. Contr., vol. 44, no. 1, pp. 121-132, Jul. 2022.

# Harnessing Ensemble in Machine Learning for Accurate Early Prediction and Prevention of Heart Disease

Mohammad Husain[1], Pankaj Kumar[2], Mohammad Nadeem Ahmed[3], Arshad Ali[4] (IEEE, Senior Member),
Mohammad Ashiquee Rasool[5], Mohammad Rashid Hussain[6], Muhammad Shahid Dildar[7]

Department of Computer Science, Islamic University of Madinah, Kingdom of Saudi Arabia[1]
Department of Technical Education, Punjab, Sector 36, Chandigarh, India[2]
Department of Computer Science, King Khalid University, Saudi Arabia[3]
Faculty of Computer and Information Systems, Islamic University of Madinah, Saudi Arabia[4]
College of Computer Science, King Khalid University, Abha, Saudi Arabia[5]
Department of Management Information Systems, King Khalid University, Abha, Kingdom of Saudi Arabia[6, 7]

*Abstract*—Cardiovascular diseases (CVDs) remain a significant global health concern, demanding precise and early prediction methods for effective intervention. In this comprehensive study, various machine learning algorithms were rigorously evaluated to identify the most accurate approach for forecasting heart disease. Through meticulous analysis, it was established that precision, recall, and the F1-score are critical metrics, overshadowing the mere accuracy of predictions. Among the classifiers explored, the Decision Tree (DT) and Random Forest (RF) algorithms emerged as the most proficient, boasting remarkable accuracy rates of 96.75%. The DT Classifier exhibited a precision rate of 97.81% and a recall rate of 95.73%, resulting in an exceptional F1-score of 96.76%. Similarly, the RF Classifier achieved an outstanding precision rate of 95.85% and a recall rate of 97.88%, yielding an exemplary F1-score of 96.85%. In stark contrast, other methods, including Logistic Regression, Support Vector Machine, and K-Nearest Neighbor, demonstrated inferior predictive capabilities. This study conclusively establishes the combination of Decision Tree and Random Forest algorithms as the most potent and dependable approach for predicting cardiac illnesses, providing a groundbreaking avenue for early intervention and personalized patient care. These findings signify a significant advancement in the field of predictive healthcare analytics, offering a robust framework for enhancing healthcare strategies related to cardiovascular diseases.

*Keywords—Heart disease; machine learning; predictive modeling; cardiovascular disorders; medical diagnosis; feature selection; model evaluation; public health*

## I. INTRODUCTION

### A. Background and Motivation

Modern lifestyles and population change have led to widespread stress, anxiety, and health issues [1]. Sedentary living has increased mortality due to chronic diseases [2-4]. The heart's vital role in transporting nutrients makes its proper function crucial [5-6]. Machine learning extracts valuable insights from large databases. Various techniques, including clustering, association, and classification algorithms, are used to predict heart disease [45]. Cardiovascular diseases cause significant mortality, warranting urgent research [7]. Chronic illnesses, like cancer and diabetes, surpass infectious diseases in causing death and disability. The epidemiologic transition marks this shift. Globally, cardiac diseases account for 17.3 million deaths yearly, projected to rise [8-9]. Machine learning aids early heart disease diagnosis. Defining disease is complex; it generally refers to disrupted bodily functions. Heart disease is universal and results from plaque buildup in coronary arteries. Plaque narrows vessels, causing reduced blood supply, leading to heart attacks or strokes. Symptoms include chest discomfort, pain, and anxiety [46]. Disease causes, recognition, diagnosis, and risk assessment are discussed. This paper delves into heart disease's global burden, machine learning's role, problem statement, research goals, and research article structure.

### B. Heart Disease Mortality Rates

Heart disease is a leading cause of death in both developing and developed countries. WHO data reveals significant mortality (region wise distribution of mortality rate is shown in Table I), with 3.8 million deaths in men and 3.4 million deaths in women attributed to heart disease [10]. In the UK, heart disease constitutes 26% of all fatalities [10]. Reports from the Australian Bureau of Statistics (ABS) and the Economic and Social Commission of Asia and the Pacific (ESCAP) indicate mortality rates ranging from 20% to 33% in 2010 [11].

TABLE I.    INCIDENCE OF HEART-RELATED DEATHS

| Sr. No. | Region | Mortality Rate |
|---|---|---|
| 1 | Australia | 33.7% |
| 2 | East Asia and Pacific Region | 35.2% |
| 3 | Middle East and North Africa | 47% |
| 4 | South Asia | 10.6% |
| 5 | Sub-Sahara in Western Africa | 13% |
| 6 | Europe | 20-26% |

Diverse regions exhibit varying heart disease-related mortality rates. Notably, heart disease accounts for 10.6% of reported fatalities [11], with 13% attributed to cardiovascular diseases. Circulatory diseases, predominantly heart diseases, dominate mortality in regions spanning Asia-Pacific, Australasia, Western Europe, and North America. Heart disease emerges as a universal cause of death, regardless of a nation's income level.

## C. Global Burden of Heart Disease

Heart disease presents a significant global challenge, impacting individual mortality, family well-being, and economic costs. In the UK, heart disease costs approximately £9 billion yearly, covering premature death and disability expenses [10]. The USA spends around $312.6 billion annually on stroke and heart disease, projected to reach $1.1 trillion by 2035 [9]. China allocates over $40 billion, constituting about 4% of GNI, to heart disease treatment. South Africa's heart disease treatment costs range from 2% to 3% of GNI, a quarter of primary care expenses. Globally, heart disease treatment cost about $370 billion in 2001, accounting for 10% of global healthcare costs [12]. Eastern Europe's high blood pressure expenses reach nearly 25% of healthcare costs. The American Heart Association (AHA) devised a method to forecast medical costs for conditions like high blood pressure, coronary artery disease (CAD), and stroke [13]. By 2030, 40.8% of Americans are predicted to have heart disease. Costs are set to rise from $320 to $818 billion between 2013 and 2030. Early diagnosis is crucial to prevent worsening conditions.

## D. Heart Disease Recognition and Diagnosis: Current Scenario

The surge in heart disease incidence stems from preventable factors [1], including unhealthy lifestyles and risk factors like poor diet, obesity, high blood pressure, and elevated triglyceride levels. Warning signs encompass insomnia, abnormal heartbeat, leg swelling, and rapid weight gain [2], often misinterpreted in elderly populations. Growing hospital and research data availability aids precision diagnosis and early detection. AI and ML revolutionize healthcare, enhancing diagnostics, data analysis, and risk prediction. Genetic data analysis benefits from machine learning, expanding medical evaluations and pandemic anticipation. Cardiovascular diseases account for over a third of annual deaths [6], attracting machine learning application in detecting heart disease from medical databases. Diagnostic accuracy, speed, and lifesaving insights improve through these procedures [7].

Dataset diagnosis draws on multiple patient pathology features [46], influenced by varying factors. Critical indicators often determine disease presence. Specialized feature selection enhances predictive accuracy. Addressing class imbalance and dataset rebalancing improves model reliability. Machine learning excels in complex, nonlinear problems, solving classification and prediction tasks like prenatal cardiac defect diagnosis [47] and ECG early warning systems [48]. Ensemble learning's base underlies many techniques, combining classifiers for enhanced performance. Xgboost mitigates overfitting.

Research presents numerous models for cardiac disease classification and prediction. Computerized classifiers assess congestive heart failure risk. Machine learning achieved 93.3% sensitivity and 63.5% specificity [51]. ECG-based deep neural networks improve performance [52]. Clinical decision support systems aid early heart failure detection [53]. SVM identifies diabetes and predicts heart disease with 94.60% accuracy [55]. In "curse of dimensionality," massive data's exponential growth hampers analysis, causing overfitting. Weighting characteristics reduce dataset duplication, easing processing [57, 58, 59]. Feature engineering and selection methods decrease dataset dimensionality [50].

Despite preventability efforts, heart disease persists globally. Pharmacies and health maintenance tests are crucial for rising heart disease rates. Expensive screening tests are used initially, prompting the need for cost-effective community-level alternatives. Identifying risk factors like age, alcohol, diet, smoking, and inactivity is vital to combat heart disease. Exposure to these factors increases hypertension, diabetes, dyslipidemia, obesity, and stroke risks [16].

Heart disease's high mortality demands accurate diagnosis tools. A systematic, accurate diagnostic tool based on death rates, disability rates, and costs is needed. Screening tools for cost-effective early diagnosis exist but require invasive blood sampling [16]. Main objective of this work is to study ML Algorithms (LR, KNN, SVM, RF, and Decision Tree), optimize algorithms to combat overfitting, apply ML for Classification, evaluate, and compare performance metrics.

The study evaluates and compares classifiers such as decision trees, Naive Bayes, logistic regression, SVM, and random forests. It suggests an innovative ensemble classifier strategy, which combines both strong and weak classifiers. This approach is designed to accommodate diverse sample requirements for training and validation, ensuring a robust and reliable predictive model for heart problems. By harnessing the synergistic strengths of multiple classifiers, this research aims to provide a comprehensive and accurate prediction framework for cardiovascular diseases, thereby contributing significantly to the advancement of predictive healthcare analytics.

## E. Research Paper Outline

The Research paper is organized into five sections including conclusion and discussion. Section I introduce the spread of heart disease, its prevalence, diagnosis, and economics of early cure including research goals. Section II provides an in-depth review of heart disease prediction using machine learning techniques. The Section III is used to describe machine learning techniques and their applications. Performance evaluation via various techniques is highlighted in Section IV. Finally, the paper is concluded in Section V with limitations of proposed technique and future research directions.

## II. LITERATURE REVIEW

This section provides an in-depth exploration of the significant contributions made by researchers in the realm of heart disease assessment using various machine learning techniques. The focal point is on recognizing the importance of

early diagnosis and prognosis, while concurrently highlighting the gaps and limitations present within the existing literature.

Ignoring heart issues can be detrimental, with men at higher risk [10]. A pivotal dataset from 1988 combines Cleveland, Hungary, Switzerland, and Long Beach V data. 80% of heart disease can be averted through healthy living [14]. Primary, secondary, and tertiary preventions obstruct disease progression [15]. Early diagnosis reduces serious illness and cost. A reliable tool for high-risk classification is crucial. AHA's goals could prevent millions of heart disease deaths [14]. Early detection prevents severe conditions [15]. Resource constraints in LMICs require cost-effective, community-level screening for higher-risk individuals. Early prediction and cost-effective prevention strategies are essential [15].

Researchers have harnessed supervised machine learning techniques to predict heart disease. Nguyen and Davis [23] introduced the KMIX algorithm for heart ailment prognosis. Shouman, Turner, and Stocker [24] advanced Naive Bayes through K-Means clustering. Tsipouras et al. [25] innovated a fuzzy rule-based model. Aqueel and Hannan in [26] integrated SVM, genetic algorithms, rough set theory, association rules, and neural networks. Amin, Agarwal, and Beg [27] crafted a hybrid model integrating neural networks and genetic algorithms. Chaurasia and Pal in [28] envisioned heart disease forecasts by deploying Naïve Bayes, decision trees, and bagging. Bialy et al. [29] forged a hybrid model that amalgamated Bay's theorem and Perceptron. In Table II some of the recent work is listed with research methodology, limitations, and contribution. Modepalli et al. [52] embraced a hybrid approach of DT and RF. L. Sathish Kumar and A. Padmapriya [58] employed the ID3 algorithm to anticipate diseases.

Some latest results show that in one study, logistic regression exhibited notable accuracy, achieving 90.16% on the Cleveland dataset, while AdaBoost outperformed with 90% accuracy on the IEEE Dataport dataset [60]. Another comparative analysis scrutinized traditional machine learning methods against deep learning algorithms, highlighting the superiority of artificial neural networks (ANN). The ANN model demonstrated a remarkable accuracy of 93.44%, surpassing the support vector machine (SVM) model by 7.5% [61].

TABLE II.        SUMMARY OF LITERATURE REVIEW

| Reference No. | Methodology | Outcome | Advantages | Limitations |
|---|---|---|---|---|
| [17] | Machine Learning Models for CHD | Risk estimation over short and long term | Improved risk assessment | Focus on short-term forecasting |
| [18] | Cross-Validation and Multi-class Classification | Robust prediction model | Effective evaluation on multiple classes | Focus on cross-validation |
| [19] | Heart Rate Variability Analysis | CAD diagnosis using HRV | Utilization of medical domain knowledge | Focus on HRV analysis |
| [20] | Neural Network Model | Risk assessment using neural networks | Utilizing AI for risk assessment | Specific to neural network model |
| [21] | Various Machine Learning Algorithms | Heart disease prediction using ML | Comparative evaluation of algorithms | Focus on multiple machine learning models |
| [22] | Decision Trees and Risk Model | Risk assessment model for CHD | Effective use of decision trees | Focus on specific algorithms |
| [23] | KMIX Algorithm for Clustering | Improved clustering for disease prediction | Enhanced performance with KMIX algorithm | Specific to KMIX clustering method |
| [24] | K-Means with Naive Bayes | Enhanced prediction using K-Means and NB | Improved handling of continuous attributes | Specific to K-Means and NB |
| [25] | Fuzzy Rule-Based Model | CAD prediction using fuzzy rules | Improved classification with fuzzy rules | Utilization of fuzzy rules |
| [26] | Ensemble Techniques with Genetic Algorithms | CHD diagnosis using various algorithms | Enhanced predictive capability | Focus on ensemble and genetic algorithms |
| [27] | Hybrid Model (Neural Network and Genetic Algorithm) | Initial risk assessment model | Utilizing hybrid model for prediction | Specific to neural network and GA |
| [28] | Naïve Bayes, Decision Trees, Bagging | Accurate heart disease prediction | Effective use of multiple algorithms | Specific to certain algorithms |
| [29] | Ensemble Techniques with Weighted Average | CAD assessment using ensemble methods | Improved accuracy with ensemble approach | Focus on ensemble techniques |
| [52] | Artificial Intelligence for CHD | Severity prediction using K-Star algorithm | Utilizing AI for cardiac diagnosis | Focus on severity prediction |
| [58] | ID3 Algorithm in TV and Mobile Phones | Disease prediction and prevention | Effective education and prevention | Specific to certain algorithms |

Furthermore, a distinct research endeavor proposed an innovative heart disease prediction model. This model incorporated embedded feature selection techniques and deep neural networks, resulting in an impressive accuracy of 98.56% on the Kaggle dataset [62]. Additionally, a neural networks model utilizing a Multilayer Perceptron (MLP) achieved commendable accuracies, recording 85.71% on the UCI Heart Disease dataset and 87.30% on the cardiovascular disease dataset [63].

### A. Research Gaps

Despite the strides in heart disease prediction, the extant literature grapples with several limitations:

- Crafted models struggle with generalizability and potential sluggishness due to intricate risk rules.

- Experimentation tools entail complications and inherent limitations.

- Majority of models are circumscribed to clinical attributes, neglecting non-invasive risk elements.

- Scarce research leverages multiple feature selection techniques alongside their mean values.

A pressing need exists for further exploration into novel heart disease revelations and their effective integration into machine learning techniques. Continued research is essential to heighten diagnostic precision through machine learning methods and surmount the prevailing gaps in heart disease anticipation and detection.

### III. MACHINE LEARNING METHODS FOR HEART DISEASE PREDICTION

Machine learning techniques are used to extract hidden information in an explicit structure from these large datasets because the medical industries are overrun with noisy and incomplete data. Machine learning techniques should be used in the healthcare industry to support specialists rather than replace them [54]. The feature selection methods used to identify the significant non-invasive subset of risk attributes for the early diagnosis of heart disease are described in this Section. The machine learning methods used to create a risk evaluation model are covered in this section. Various performance measures are used in this section to assess the risk models' performance. The importance of non-invasive risk factors for the initial diagnosis and care of cardiac patients is also discussed in this section.

Exploring the heart disease dataset provides valuable insights that can significantly aid in early detection and prediction of cardiovascular conditions. In this Section, Davis' machine learning methodology was employed in the study to construct a comprehensive cardiovascular disease model. The focal point of this Section lies in outlining the research procedures, designing the study's framework, and expanding its applicability through well-defined objectives. By harnessing the power of machine learning techniques, this research effectively identifies a substantial subset of risk factors crucial for the initial prognosis of individuals with heart disorders.

### A. The Methodology of Prediction

The process of transforming raw data into a dataset that can be used to produce knowledge for users is referred to as "machine learning" and a machine learning methodology is a method that uses alternative techniques to accomplish this transformation. The utilization of this methodology in particular is warranted due to the fact that it exemplifies the objectives of our research. The following is an outline in Fig. 1. The first step of the process is called data selection, and it entails selecting the pertinent information about heart disease from a variety of different sources so that it can later be entered into the standard database.

*1) Data Preparation:* In the first step, known as "data preparation," the dataset containing information about heart disease is analyzed and prepared so that the machine learning algorithms can derive useful insights from it and achieve the best possible results.

*2) Data Task Filter:* In this step, the heuristic decision rules are used to establish expected outcomes for the prognosis of heart disease in subsequent steps. The dataset that was selected is then stored in what is called the "Machine learning Task Warehouse."

*3) Selecting Appropriate Algorithms and Datasets:* It is for the Task Specified in Step 3. This step involves selecting an appropriate algorithm and dataset for the task that was specified in Step 3.

*4) Comparison and Evaluation:* The results of the classification are compared to one another and estimated using a variety of different machine learning evaluation metrics during this phase.

In the process of developing new models, the recently finished supervised classification models have been filed away in the data warehouse in order to be ready for any upcoming issues with prediction. For each new prediction task, the procedure starts over at step three and continues through step five.
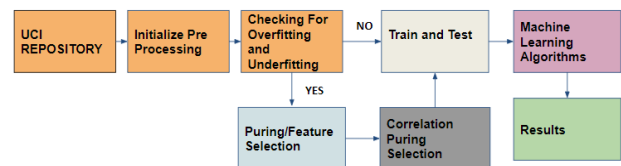


Fig. 1.   Detail steps of research design.

### B. Exploratory Data Analysis (EDA) Process

Fundamental statistical descriptions are conducted to enhance understanding of the myriad attribute values within the Kashmir heart disease dataset. Knowledge of these basic statistics facilitates addressing noisy values, detecting outliers, and handling missing values. The dataset contains both nominal and numerical values, all serving as risk factors for coronary heart disease. Simple mean imputation is applied to address missing numerical values, while mode imputation is used for missing values in categorical data.

## C. Examination of Class Imbalances and Distributional Issues

Before engaging in any operations related to heart disease dataset, assessing class balance is crucial. Highly imbalanced data can lead to biased machine learning algorithms. Statistical analysis is applied to the data to evaluate its kurtosis, skewness, and class balance. Skewness assesses symmetry to determine if data distribution is equal on both sides of the center point. Kurtosis identifies whether data tails are light or heavy compared to a normal distribution. Skewness and Kurtosis tests reveal that the Kashmir heart disease dataset follows a normal distribution.

## D. Establishing Feature Correlations

Since datasets can contain intricate interconnections between variables, quantifying the degree of attribute relationships is vital. The correlation process involves assessing the level of connection between dataset attributes. Understanding these connections is essential for data preparation before applying machine learning algorithms. Pearson's correlation method is used to explore the relationship among heart disease attributes. A heatmap depicts Pearson's correlation coefficients applied to heart disease variables (see Fig. 2).

The heatmap grid showcases associations between cardiovascular disease-related factors and associated coefficients. The matrix presents all attributes horizontally across the top and vertically down the side, offering correlations among feature combinations. The diagonal line's connection from bottom right to top left indicates perfect correlation between attributes and themselves. Correlation coefficients near zero suggest weak relationships between heart disease attributes, while values of 1 and -1 signify ideal positive and negative correlations, respectively.
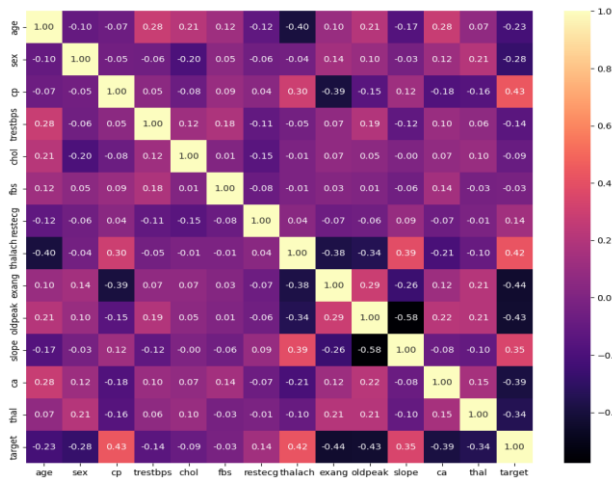


Fig. 2. Correlation in risk attributes through heat map representation.

## E. Feature Selection

Feature selection is crucial as irrelevant or redundant attributes can impede classifier performance. To attain a non-invasive subset of risk attributes for precise heart disease prediction, the heart disease dataset (as listed in Table IV) undergoes five distinct Feature Elimination techniques. These techniques assign values to potential risk factors based on their disease prediction accuracy, assigning weights from 0 to 1 to each attribute associated with coronary heart disease. The final weights are determined by individual feature selection techniques, where attributes with mean values close to 1 are considered significant, while those near 0 are less significant.

These heart disease-linked characteristics are presented in descending order of mean values derived from five distinct feature selection strategies in Table V. Attributes with higher weights are more important for predicting early heart disease, while those with lower values are less significant. The model predicting the risk of heart disease development is constructed using the highly weighted significant subset of risk factors.

*1) Feature selection techniques*: Precise and concise prediction model subsets are identified using feature selection techniques [30]. To obtain the best non-invasive subset of risk factors for heart disease prediction, this research investigates a combination of filter, wrapper, and embedded feature selection methods.

- Extra Tree Classifier: The extra tree classifier, also known as extremely randomized trees, is an ensemble learning technique creating multiple trees without eliminating any existing ones. Decision tree nodes are divided through random splits, enhancing accuracy while significantly reducing the computational load associated with determining optimal cut-points in random forests and standard trees [31].

- Gradient Boosting Classifier: Gradient boosting is employed to address classification and regression challenges. It entails constructing decision trees in a greedy manner to optimize a loss function, adding these trees one at a time to minimize the loss function [32].

- Random Forests: Random forests involve decision tree predictors for regression and classification tasks, using multiple decision trees in a randomly selected training set to counter individual decision tree overfitting [33]. Further explanation of the random forest classifier can be found in the machine learning techniques section.

- Recursive Feature Elimination: Recursive feature elimination (RFE), a greedy optimization technique, builds the feature model until all features are used. Features are then ranked based on their elimination order [34].

- XG Boost Classifier: The XG Boost classifier employs a gradient boosting algorithm with optimized regularization to counter bias and overfitting. Its scalability enables swift learning and efficient memory usage [35].
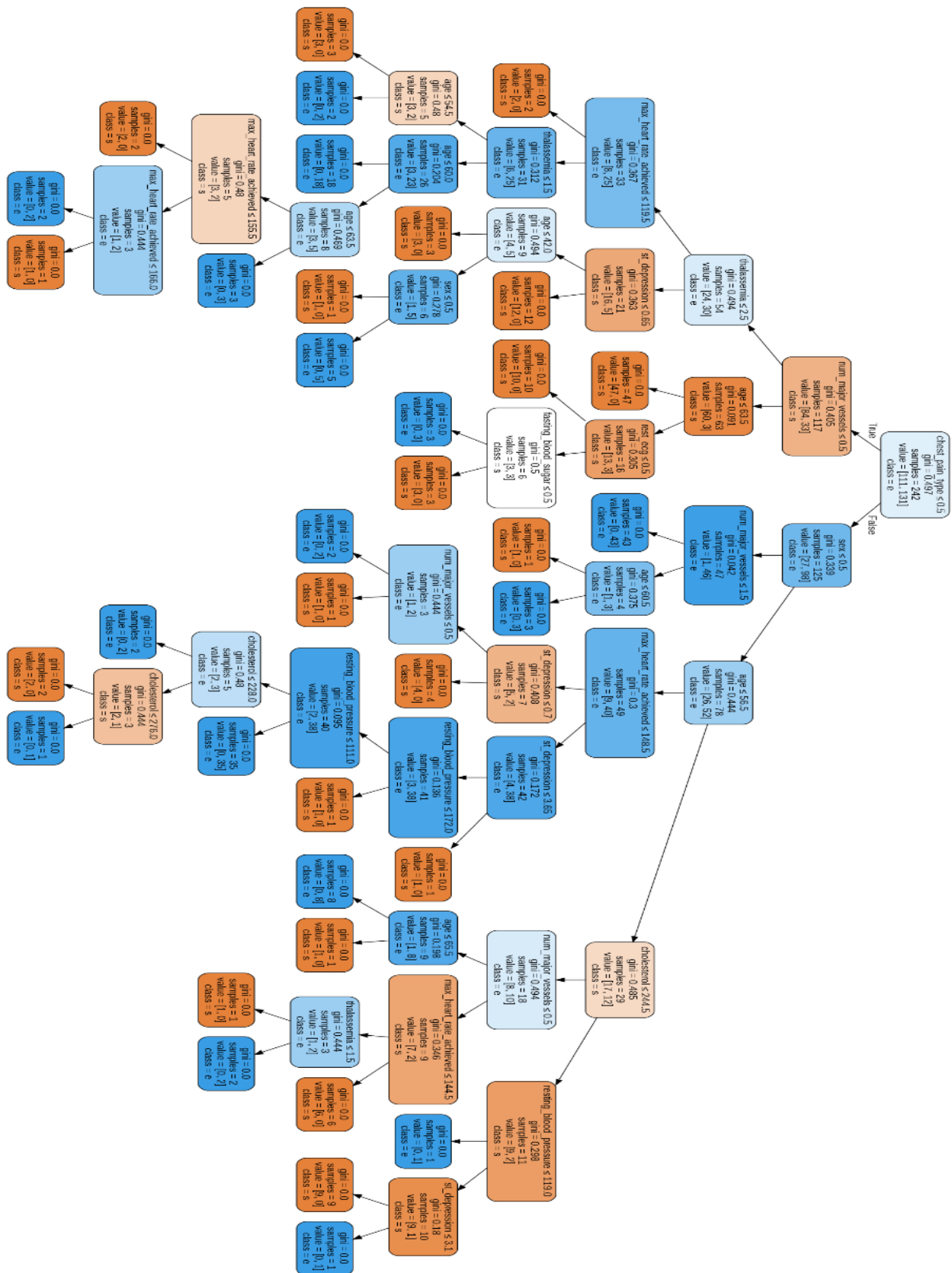
Fig. 3.    Decision tree model working for heart disease prediction.

### F. Predictive Analysis

Machine learning tasks capitalize on discovered patterns to learn from the machine learning process. These tasks are typically categorized into predictive and descriptive categories [36]. Predictive tasks focus on predicting the value of a dependent (target) attribute based on independent (exploratory) attributes. Descriptive tasks aim to extract patterns describing underlying relationships within data, often requiring post-processing techniques for validation and explanation due to their exploratory nature [37].

*1) Machine learning techniques*: Predicting heart condition from different symptoms is a stratified problem that is bound to erroneous assumptions and has impulsive effects. We use various machine learning methods to extract knowledge from the heart disease dataset. The purpose of blending machine learning methods in health care is not to take over specialists or assistants, but to give support to where they struggle [38]. Some of the popular Machine Learning algorithms are shown in Fig. 4 and described below:
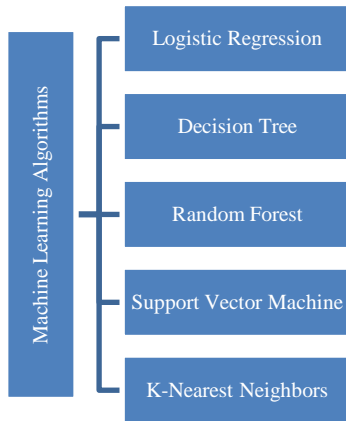


Fig. 4. Machine learning algorithms.

- Decision Tree: The decision tree is a widely used tool, especially for classification tasks [39]. It is constructed using a top-down, recursive divide-and-conquer approach, following a greedy (nonbacktracking) strategy. This is depicted in Fig. 4. There are various types of decision trees, distinguished by the mathematical model they employ to select the attribute for splitting, thereby forming decision tree rules. The attribute that effectively divides the tuples into distinct classes is chosen based on the Information Gain attribute selection measure. The Information Gain approach aims to maximize the reduction in uncertainty by selecting the splitting attribute with the lowest entropy value. The Information Gain for each attribute is determined using Eq. (1):

$$Gain\,(A) = Info\,(D) - InfoA(D) \tag{1}$$

Where:

- Info (D) represents the entropy of the entire dataset.

- InfoA (D) represents the weighted average of the entropies of subsets obtained by splitting based on attribute A.

The entropy of a set is calculated using Eq. (2):

$$Info\,(D) = \Sigma - p * log2(p)\square \tag{2}$$

where, p is the proportion of instances belonging to a specific class.
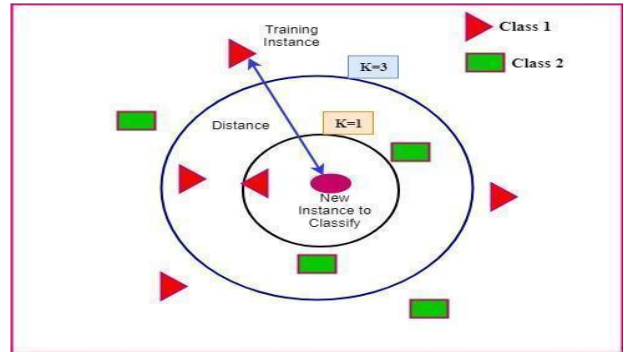


Fig. 5. K nearest neighbour classification.

- K-Nearest Neighbor (KNN): K-Nearest Neighbor (KNN) is a fundamental instance-based machine learning technique that operates in a non-parametric manner [40, 49]. It relies on learning by analogy, where a new unclassified record is compared to existing records using a distance metric. The class of the closest existing record is then assigned to the new unclassified record. Fig. 5 provides an example of KNN classification. The optimal value of k (the number of neighbors) is typically determined experimentally. This involves starting with k = 1 and gradually increasing k to account for more neighbors. The error rate of the classifier is calculated using a test set. In the KNN algorithm, a new instance is classified based on its proximity to its neighbors, determined by a distance function. Various distance measures such as Euclidean, Manhattan, and Minkowski can be utilized. In this study, due to the nature of the heart disease data, the Euclidean distance measure is used. To prevent attributes with higher values from dominating those with lower values, attribute values are normalized before applying the Euclidean distance measure. The Min-Max normalization technique is employed, which transforms a numerical attribute's value P to a value P| in the range [0, 1]. The KNN technique is used in this study for predicting heart disease.
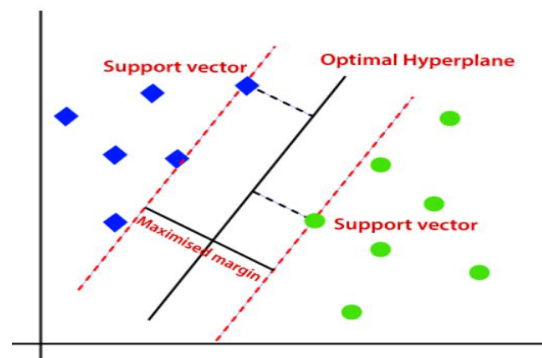


Fig. 6. Linear SVM classifier for two-class representation.

- Support Vector Machine (SVM): Support Vector Machine (SVM) is a supervised machine learning technique used for both classification and regression tasks. SVM works by translating the original training data into a higher-dimensional space through a nonlinear mapping. It seeks to find the best separating hyperplane in this new dimension. Support vectors and margins are utilized by SVM to determine this hyperplane [41]. The linear support vector machine is illustrated in Fig. 6, where red circles denote data points of class x2, and light green circles represent data points of class x1. However, if there is no obvious hyperplane in the original feature space, SVM requires moving to a higher-dimensional view known as kernelizing. The principle behind kernelizing is that the data will be mapped into higher dimensions until a hyperplane can be established to separate it. The choice of the SVM's kernel function, such as polynomial, radial basis, and Gaussian kernel functions, plays a critical role. There are other kernel functions available as well, in addition to the ones mentioned.

- Random Forests: Random Forests are an ensemble learning technique that utilizes a collection of individual decision trees for both classification and regression tasks. They are designed to address the issue of overfitting that can occur with individual decision trees. In random forest classification, the final class of a test object is determined by the majority votes from each decision tree in the forest [42]. Random Forests have significantly extended bagging, a technique that aggregates a large set of decorrelated trees. The process of the random forest algorithm is depicted in Fig. 7, where each tree is grown using a different subset of the original data. In each of the k iterations, approximately one-third of the samples are left out from the new bootstrap training set and are not used in constructing the tree. The class with the highest number of votes from the trees in the forest becomes the final classification for a given sample. The random forest algorithm is applied in this study for diagnosing and predicting heart disease, and Section IV provides further details on the outcomes.

- Naive Bayes: Naive Bayes is a classification algorithm that operates based on statistical probabilities and follows the principles of the Bayesian theorem. It is particularly effective when dealing with high-dimensional inputs. The algorithm works under the assumption of "class conditional independence," which means that the attribute values' impact on a specific class is considered unrelated to the outcomes of other attributes. This assumption is referred to as "naive" because it simplifies calculations [43]. The Naive Bayes classifier can handle both continuous and categorical variables, and it can accommodate any number of independent variables. By assuming that the probabilities are independent of each other, Naive Bayes simplifies probability calculations, leading to a fast and efficient method. In this study, the Naive Bayes algorithm is employed using the non-invasive

risk attributes to predict and diagnose heart disease at its early stages. Section IV provides a detailed discussion of the Naive Bayes model's predictions for heart disease.
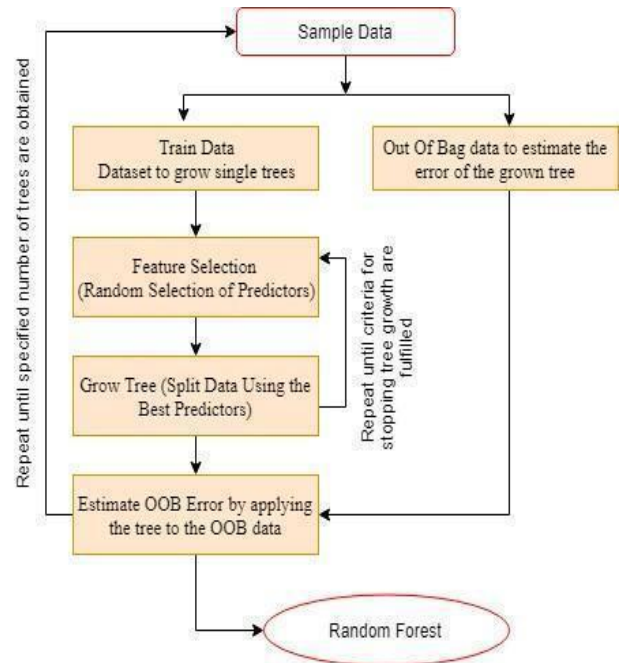


Fig. 7. Random forest algorithm working.

*2) Model evaluation techniques*: Model evaluation is a critical aspect of practical machine learning development. In order to interpret patterns from the provided dataset, systematic methods are required to assess the effectiveness of machine learning techniques and to compare them, helping to decide which method to use for a given problem. The performance of algorithms in classification problems can be evaluated using various metrics, including the confusion matrix, cross-validation, error rate, sensitivity, specificity, accuracy, and precision. These evaluation metrics are discussed below [44]:

*a) Confusion Matrix*: The confusion matrix is a fundamental tool for assessing performance in classification problems. It is particularly useful for understanding the types of classification errors that can occur in two-class classification scenarios. The confusion matrix provides insight into how well the model's predictions align with the actual outcomes. In a two-class confusion matrix, as shown in the Table III below, various classifications are categorized based on their correctness or incorrectness:

- True Positives (TP): Instances that are correctly classified as positive.

- False Negatives (FN): Instances that are actually positive but are incorrectly classified as negative.

- False Positives (FP): Instances that are actually negative but are incorrectly classified as positive.

- True Negatives (TN): Instances that are correctly classified as negative.

The confusion matrix allows for a deeper understanding of the model's performance and the types of errors it makes, such as Type We and Type II errors.

TABLE III.    CONFUSION MATRIX FOR BINARY CLASSIFICATION

| | | Predicted Values | |
|---|---|---|---|
| | | Positive | Negative |
| **Actual Values** | **Positive** | True Positive (TP) | False Negative (FN) |
| | **Negative** | False Positive (FP) | True Negative (TN) |

- Error Rate (Misclassification Rate): The error rate, also known as the misclassification rate, is a measure that quantifies the proportion of misclassified instances in a classification model. It's a combination of both training errors and generalization errors.

- Training Errors: These are the mistakes made by the model when classifying instances within the training dataset.

- Generalization Errors: These are the expected mistakes that the model will make when classifying instances that it hasn't seen before, i.e., on unseen data.

The goal of a good classification model is to have both low training and generalization errors. This indicates that the model has learned the underlying patterns in the data without overfitting to the training data.

The error rate can be calculated using the formula in Eq. (3):

$$Error\ Rate = \frac{(False\ Positives + False\ Negatives)}{(Total\ Positive + Total\ Negative)} \qquad (3)$$

Where False Positives are instances that are wrongly classified as positive, False Negatives are instances that are wrongly classified as negative, and Total Positive and Total Negative are the total number of positive and negative instances, respectively.

- Cross-Validation: Cross-validation is a technique used to estimate the performance of a machine learning model on unseen data. It involves dividing the dataset into multiple subsets (folds), using some folds for training and others for testing. This process is repeated multiple times with different combinations of training and testing sets. By evaluating the model's performance across different subsets of data, cross-validation provides a more robust estimate of its generalization ability. In a common method called k-fold cross-validation, the dataset is divided into k subsets of approximately equal size. The model is trained on k-1 folds and tested on the remaining fold in each iteration. The results from all iterations are then averaged to provide an overall assessment of the model's performance. Cross-validation helps to mitigate the risk of overfitting and provides a more accurate estimation of how well the model will perform on new, unseen data.

## IV. RESULTS AND DISCUSSION

In conclusion, the development of a robust risk evaluation model for cardiac disorders involves careful selection and preprocessing of data, integration of diverse information sources, and the utilization of appropriate algorithms. By prioritizing non-invasive risk factors and optimizing data quality, accurate and reliable risk assessment strategies can be implemented.

### A. Dataset Selection

For the development of the risk evaluation model, we sourced a dataset from the Kaggle Machine Learning library. This dataset comprises 1025 data points, each characterized by 14 distinct attributes, encompassing 13 predictive features and 1 target class. These attributes encompass various factors such as age, sex, chest pain, high blood pressure, cholesterol levels, fasting heart rate, ECG readings, and more [5]. In order to comprehensively analyze the risk factors associated with heart disease and to construct a highly accurate model, five different algorithms are employed. The field of cardiac disorder detection encompasses various tests, some of which require invasive procedures and multiple blood tests. To implement more practical risk recognition strategies, a focus on non-invasive risk factors is essential. These factors, such as age, height, weight, and smoking habits, can be easily obtained without the need for complex equipment. While measurements like body weight and blood pressure do require devices, these tools are readily available at home or local pharmacies, eliminating the necessity for hospital-based procedures for data acquisition. Data fields are shown in Table III.

### B. Data Balancing

Notably, many medical databases exhibit an imbalanced distribution of positive and negative samples. To enhance the model's reliability, it may be necessary to apply specific data processing techniques to rectify this imbalance [56]. Moreover, real-world data often contains duplicates and missing values, which can distort the analysis. Through careful data preprocessing, including techniques like smoothing, normalization, and grouping, we ensured that the input data was accurate, devoid of noise, and effective for analysis [6].

### C. Data transformation

The process of transforming raw data into a more understandable format involves translation. This translation process is supplemented by steps such as smoothing, normalization, and grouping to ensure that the data is prepared optimally for analysis. Moreover, integration of information from various sources is often required to produce refined and comprehensive datasets.

### D. Data Preprocessing

Within the dataset, 526 instances represent individuals with cardiac disease, while 499 instances pertain to individuals without the condition. While it can be challenging to limit the amount of data collected, it's crucial to present the data effectively to derive meaningful insights. In certain cases, specific attributes may hold a high correlation with the target variable. For instance, in analysis, the fasting blood sugar attribute displayed significant correlation, leading to eliminating the corresponding column to enhance the model's

accuracy. Table V lists out the ranking of different attributes as per the importance of attributes.

*1) Splitting data into test train set*: Following data preprocessing, the dataset is organized into training and validation subsets into 80:20 ratio. The performance of different algorithms is then assessed to ascertain their predictive capabilities [7]. The process of data preparation, including feature selection and data uniformity, can significantly enhance the dataset's utility and subsequently improve the accuracy of the model.

TABLE IV.    THE HEART DISEASE DATASET ATTRIBUTES

| Variable Name | Role | Type | Units | Missing Values |
|---|---|---|---|---|
| Systolic BP | Feature | Integer | mm Hg | no |
| Diastolic BP | Feature | Integer | mm Hg | no |
| BMI | Feature | Integer | Number | no |
| Age | Feature | Integer | Years | no |
| Healthy Diet | Feature | Categorical | No Unit | no |
| Hereditary | Feature | Categorical | No Unit | no |
| Smoking | Feature | Categorical | Binary | no |
| Physical Activity | Feature | Categorical | Binary | no |
| Socio-Economic Level | Feature | Categorical | No unit | no |
| Sex | Feature | Binary | No Unit | no |
| Alcohol Consumption | Feature | Categorical | Number | no |
| CHD | Target | Integer | No unit | no |

TABLE V.    MEAN RANKING OF WEIGHTAGE OF ATTRIBUTES

| Sr. No. | Attributes | Mean ranking of attributes |
|---|---|---|
| 1 | Systolic BP | 0.82 |
| 2 | Diastolic BP | 0.80 |
| 3 | BMI | 0.78 |
| 4 | Age | 0.76 |
| 5 | Healthy Diet | 0.54 |
| 6 | Hereditary | 0.42 |
| 7 | Smoking | 0.28 |
| 8 | Physical Activity | 0.24 |
| 9 | Socio-Economic Level | 0.16 |
| 10 | Sex | 0.14 |
| 11 | Alcohol Consumption | 0.12 |

*E. Experimental Results of the Proposed Machine Learning Techniques*

The existing models employed for assessing the risk of heart disease have demonstrated inherent flaws that undermine their effectiveness. These models often yield inconsistent results when applied to diverse datasets, thereby compromising their reliability. In this study, the focus is on leveraging machine learning techniques, specifically Decision Tree (DTC), K-Nearest Neighbor (KNN), Random Forest (RFC), Support Vector Machine (SVM), and Naive Bayes (NBC), to extract objective and dependable outcomes from the cardiovascular disease dataset. To achieve this, a range of performance metrics relevant to the medical domain, including sensitivity, specificity, accuracy, and precision, are employed to ensure the generation of accurate and reliable results. The

following subsections elucidate the experimental findings yielded by various models in the context of disease assessment.

The central aim of this study revolves around predicting the likelihood of an individual developing heart disease. To fulfill this objective, a variety of supervised classification approaches, including Support Vector Machine, Random Forest, K-Nearest Neighbor, and Logistic Regression, are explored. The experimentation encompasses the utilization of diverse computational models, particularly Decision Trees, facilitated by the SkLearn package. The experimental setup utilized a 6th generation Intel Core i3 processor with a 3300H CPU, operating at up to 2.1 GHz, and 4 gigabytes of RAM. A prompt data analysis procedure was employed to swiftly provide a comprehensive accuracy assessment for the adopted methods. The dataset partitioning involved allocating 55% (563 instances) of the data for training purposes and 45% (462 instances) for testing purposes. The subsequent graph depicts the distribution of training and testing activities undertaken during the study:
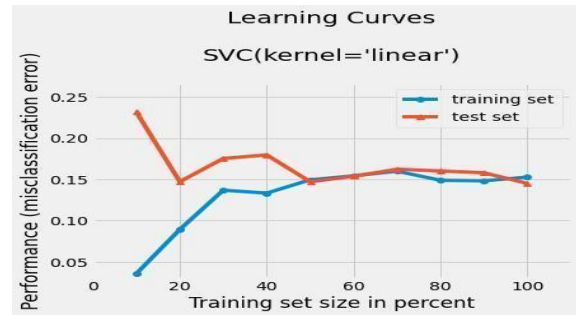


Fig. 8.    SVM train-test split.
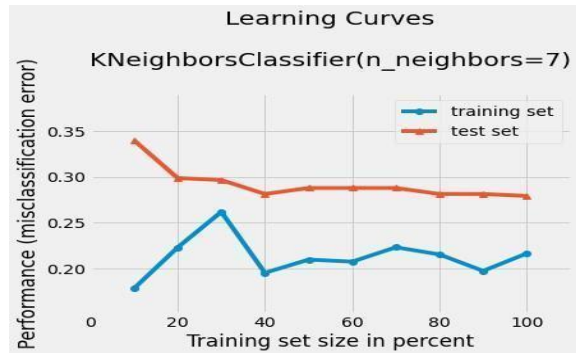


Fig. 9.    LR train-test split.
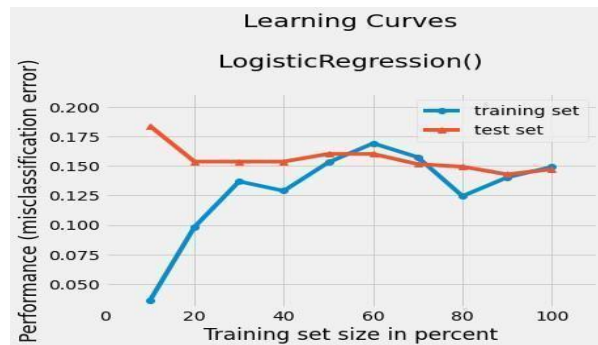


Fig. 10.  KNN train-test split.

TABLE VI.     CONFUSION-MATRIX DT

|  | Predicted(N) | Predicted(P) |
|---|---|---|
| Actual(N) | 223 (TN) | 5 (FP) |
| Actual(P) | 10 (FN) | 224 (TP) |

TABLE VII.     CONFUSION-MATRIX SVM

|  | Predicted(N) | Predicted(P) |
|---|---|---|
| Actual(N) | 179 | 49 |
| Actual(P) | 19 | 215 |

TABLE VIII.     CONFUSION-MATRIX RF

|  | Predicted(N) | Predicted(P) |
|---|---|---|
| Actual(N) | 216 | 10 |
| Actual(P) | 5 | 231 |

TABLE IX.     CONFUSION-MATRIX LR

|  | Predicted(N) | Predicted(P) |
|---|---|---|
| Actual(N) | 183 | 48 |
| Actual(P) | 19 | 214 |

TABLE X.     CONFUSION-MATRIX KNN

|  | Predicted(N) | Predicted(P) |
|---|---|---|
| Actual(N) | 165 | 58 |
| Actual(P) | 35 | 204 |

TABLE XI.     MODEL EVALUATION RESULTS IN %

| Algorithm Used | Accu-racy | Precision | Recall | F1-score |
|---|---|---|---|---|
| LR Classifier | 85.93 | 81.68 | 91.85 | 86.47 |
| SVM Classifier | 85.28 | 81.44 | 91.88 | 86.35 |
| KNN Classifier | 79.87 | 77.86 | 85.36 | 81.44 |
| DT Classifier | 96.75 | 97.81 | 95.73 | 96.76 |
| RF Classifier | 96.75 | 95.85 | 97.88 | 96.85 |

Fig. 8 to 10 showcase the division of the test dataset and the train dataset's performance, indicating that optimal performance was achieved within the 60%–80% split range. Several options were experimented to find out the best test train split. The binary label's confusion matrix for each tested method is depicted in Tables VI to X. While accuracy is a valuable metric, we place greater significance on precision, recall, and the F-1 score, all of which can be found in Table XI. Among the methods tested, K-Nearest Neighbor (KNN) yields the least favorable results, while regression and Support Vector Machine (SVM) methods perform moderately. Notably, Decision Tree and Random Forest methods exhibit the highest accuracy and F-1 score, as evidenced by this dataset. Thus, it can be inferred that Random Forest is a versatile method capable of achieving substantial accuracy with ease.

The table presents the results of different classification algorithms employed to predict heart disease, showcasing their performance metrics. These metrics are vital in assessing the accuracy and effectiveness of each algorithm in identifying individuals at risk of cardiovascular or heart-related ailments.

Logistic Regression (LR) Classifier achieved an accuracy of 85.93%, meaning it correctly predicted the presence or absence of heart disease in individuals 85.93% of the time. Its precision, which measures the accuracy of its positive predictions, stood at 81.68%, indicating that 81.68% of the cases it classified as positive were indeed true positives. With a recall rate of 91.85%, this model identified 91.85% of the actual positive cases. The F1-score, a balance between precision and recall, was 86.47%.

The Support Vector Machine (SVM) Classifier, on the other hand, achieved an accuracy of 85.28%. It exhibited a precision of 81.44%, indicating that 81.44% of its positive predictions were accurate, while its recall rate was 91.88%. The F1-score for this model was 86.35%.

The K-Nearest Neighbor (KNN) Classifier exhibited an accuracy of 79.87%, with a precision rate of 77.86%, suggesting that 77.86% of its positive predictions were correct. It had a recall rate of 85.36%. The F1-score for KNN was 81.44%.

Now, the Decision Tree (DT) Classifier stood out with a remarkable accuracy of 96.75%. Its precision rate was an impressive 97.81%, indicating a high accuracy in positive predictions. The model captured 95.73% of the actual positive cases (recall), resulting in a high F1-score of 96.76%.

Lastly, the Random Forest (RF) Classifier shared the same accuracy as the Decision Tree at 96.75%. It had a precision rate of 95.85% and an outstanding recall rate of 97.88%. The F1-score for Random Forest was 96.85%.

In summary, the Decision Tree and Random Forest classifiers exhibited the highest accuracy and strong F1-scores among the algorithms, signifying their effectiveness in predicting heart disease. These models excelled in both accurately identifying positive cases and capturing a substantial portion of actual positive cases. These results emphasize the potential of these algorithms in aiding the diagnosis and prediction of cardiac conditions with a high degree of accuracy.

While other machine learning algorithms, including Logistic Regression, SVM, K-Nearest Neighbor, and Random Forest, were explored, they were found to be comparatively less effective in predicting instances of cardiac illness. In essence, this research article underscores the combination of the Decision Tree and Random Forest algorithms as the most accurate approach for forecasting heart disease. This amalgamation offers a dependable means of predicting the potential development of cardiovascular or heart-related disorders in the future. While other algorithms were assessed, such as Logistic Regression, SVM, K-Nearest Neighbor, and Random Forest, they were not found to be as potent as the methods discussed in this study for predicting cardiac conditions.

## V. CONCLUSION AND FUTURE WORK

In the pursuit of advancing predictive analytics for cardiovascular diseases, this study meticulously examined various machine learning algorithms, aiming to identify the most effective approach for accurate and early prediction. The results presented in this research, encompassing a thorough analysis of different classifiers, unveil valuable insights into the realm of cardiac health forecasting.

The experiments demonstrated that the optimal performance was achieved within the 60%–80% split range of the test and train dataset. This meticulous evaluation led to the conclusion that precision, recall, and the F-1 score are pivotal metrics, often surpassing the significance of mere accuracy. Among the array of methods explored, K-Nearest Neighbor (KNN) emerged with comparatively less favorable outcomes, while regression and Support Vector Machine (SVM) methods exhibited moderate performance.

However, the spotlight of this research undoubtedly falls upon the Decision Tree (DT) and Random Forest (RF) classifiers. The DT Classifier showcased an exceptional accuracy of 96.75%, coupled with an impressive precision rate of 97.81% and a robust recall rate of 95.73%. This translated into an outstanding F1-score of 96.76%, underlining its proficiency in positive predictions. Equally noteworthy, the RF Classifier mirrored the DT's accuracy at 96.75% while achieving a remarkable precision rate of 95.85% and an outstanding recall rate of 97.88%, resulting in an exemplary F1-score of 96.85%. These results clearly indicate that the Decision Tree and Random Forest classifiers possess the highest accuracy and robust F1-scores, making them exceptionally effective in forecasting heart disease.

In contrast, Logistic Regression, SVM, K-Nearest Neighbor, and even Random Forest, despite its overall competence, fell short when compared to the superior predictive capabilities of Decision Tree and Random Forest classifiers. This study unequivocally establishes the amalgamation of Decision Tree and Random Forest algorithms as the most potent and dependable approach for predicting instances of cardiac illness. This combination not only accurately identifies positive cases but also captures a substantial portion of the actual positive instances, emphasizing their potential in aiding the diagnosis and prediction of cardiac conditions with an unparalleled degree of accuracy.

### A. Research Limitations

However, as with any research endeavor, certain limitations must be acknowledged. The study's predictive approach focuses on a subset of non-invasive attributes, potentially missing out on the broader spectrum of factors that influence heart disease risk. Additionally, while the model's performance is evaluated through metrics, usability testing of the prediction tools remains unexplored, leaving room for understanding user interaction and practical implementation challenges. Moreover, the study's reliance on a specific dataset categorized by a particular ethnic group might restrict the generalizability of the findings to other populations.

### B. Future Scope

The research's future trajectory offers opportunities for refinement and expansion. Further investigations could explore the efficiency of other robust machine learning techniques, such as genetic algorithms, neural networks, and hybrid models, to provide a comparative analysis of predictive performance. Expanding the model's scope to include additional non-invasive characteristics like socioeconomic status, depression severity, and ethnicity could enrich its accuracy and applicability. This might illuminate the relative importance of controlled non-invasive factors across various age and gender groups.

Furthermore, embracing diverse real-world datasets featuring multiple population groups and attributes can enhance the model's robustness and generalizability. An exciting future direction lies in the development of a comprehensive and universally applicable risk model. This model could not only predict cardiac disorders but also offer personalized treatment plans, amplifying its utility for medical professionals and patients alike. Through iterative refinement and continuous exploration, machine learning techniques hold the potential to revolutionize the landscape of heart disease prediction and prevention.

## REFERENCES

[1] Omran AR (2005). The epidemiologic transition: A Theory of the Epidemiology of Population Change. Milbank Mem Fund Q, volume 49 on page 509.

[2] World Health Organization (2010). Global status report on noncommunicable diseases 2010. https://www.who.int/nmh/publications/ncd_report_full_en.pdf

[3] World Health Organization (2011a). The Top Ten Causes Of Death. Accessed 18 August 2017, http://www.who.int/mediacentre/factsheets/fs310_2008.pdf

[4] National Center for Chronic Disease Prevention and Health Promotion (2013). Know the facts about heart disease. http://www.cdc.gov/heartdisease/docs/consumered_heartdisease.pdf

[5] European Public Health Alliance (2013). Cardiovascular Health Takes Center Stage in Brussels. Accessed 12 March 2016, from http://www.epha.org/a/5899

[6] Heart and Circulatory Disease Statistics (2019). British Heart Foundation. https://www.bhf.org.uk

[7] Shahwan-Akl, L. (2010). Cardiovascular Disease Risk Factors among Adult Australian Lebanese in Melbourne. International Journal of Research in Nursing, 1(1), 1-7.

[8] Economic and Social Survey of Asia and the Pacific (2010). http://www.unescap.org/stat/data/syb2009/9.Health-risks-causes-of-death.asp

[9] Huang Yanzhong, Moser Patricia, and Roth Susann (2015). Health in the Post-2015 Development Agenda for Asia and the Pacific.

[10] World Health Organization (2013c). Deaths from Coronary Heart Disease. http://www.who.int/cardiovascular_diseases/en/cvd_atlas_14_deathHD.pdf

[11] Gregory A. Roth (2017). Global, Regional, and National Burden of Cardiovascular Diseases for 10 Causes, 1990 to 2015. Journal of the American College of Cardiology. DOI: 10.1016/j.jacc.2017.04.052

[12] Ensminger, M. E., and Ensminger, A. H. (1993). Foods & nutrition encyclopaedia (Second Edition), Volume 1. CRC Press, ISBN 9780849389818

[13] Colin D. Mathers and Dejan Loncar (2006). Updated Projections of global mortality and burden of disease, from 2002 to 2030. Published online November 28. DOI: 10.1371/journal.pmed.0030442

[14] World Health Organization Press (2014). Global Status Report on Non-Communicable Diseases. https://www.who.int/nmh/publications/ncd-status-report-2014/en/

[15] Din, S., Rabbi, F., Qadir, F., and Khattak, M. (2007). Statistical Analysis of Risk Factors for Cardiovascular Disease in Malakand Division. Pakistan Journal of Statistics and Operation Research, 3(2), 117-124.

[16] Reynolds Risk Score (2015). About the Reynolds Risk Score. Accessed 10 November 2016, from http://www.reynoldsriskscore.org/home.aspx

[17] Colombet, A. Ruelland, G. Chatellier, F. Gueyffier, P. Degoulet, and M. C. Jaulent (2000). Models to predict cardiovascular risk: comparison of CART, multilayer perceptron, and logistic regression. Proc. AMIA Symp. PP. 156–60.

[18] H. Yan (2003). Development of a Decision Support System for Heart Disease Diagnosis Using Multilayer Perceptron. IEEE Int. Symp. Circuits Syst., vol. 5, pp. 709–712.

[19] Kiyong Noh, Heon Gyu Lee, Ho-Sun Shon, Bum Ju Lee, and Keun Ho Ryu (2006). Associative Classification Approach for Diagnosing Cardiovascular Disease. ICIC, 2006, LNCIS 345, pp. 721 – 727, 2006.

[20] K. U. Rani (2011). Analysis of Heart Diseases Dataset using Neural Network Approach. Int. J. Data Min. Knowl. Manag. Process, vol. 1, no. 5, pp. 1–8.

[21] M. Kumari and S. Godara (2011). Comparative Study of Machine learning Classification Methods in Cardiovascular Disease Prediction. Int. J. Comput. Sci. Trends Technol., vol. 2, no. 2, pp. 304– 308.

[22] V. Chaurasia (2013). Early Prediction of Heart Diseases Using Machine learning. Caribb. J. Sci. Technol., vol. 1, no. December, pp. 208–217, 2013.

[23] Thuy Nguyen Thi Thu, and Darryl.N. Davis (2007). A Clustering Algorithm for Predicting Cardiovascular Risk. World Congress on Engineering 2007: 354-357

[24] M. Shouman, T. Turner, and R. Stocker (2012a). Integrating Naive Bayes and K Means Clustering with different Initial Centroid Selection methods in the diagnosis of heart disease patients. airccj.org, pp. 431–436, 2012.

[25] Markos G. Tsipouras, Themis P. Exarchos, Dimitrios I. Fotiadis, Anna P. Kotsia, Konstantinos V. Vakalis, Katerina K. Naka, and Lampros K. Michalis (2008). Automated diagnosis of coronary artery disease based on machine learning and fuzzy modeling. IEEE Trans. Inf. Technol. Biomed., vol. 12, no. 4, pp. 447–58, 2008.

[26] Aqueel and S. A. Hannan (2012). Machine learning Techniques to find out Heart Diseases : An Overview. Int. J. Innov. Technol. Explore. Eng., vol. 1, no. 4, pp. 18–23, 2012.

[27] S. U. Amin, K. Agarwal, and R. Beg (2013). Genetic Neural Network Based Machine learning in Prediction of Heart Disease Using Risk Factors. ICT 2013 - Proc. 2013 IEEE Conf. Inf. Commun. Technol., no. ICT, pp. 1227–1231, 2013.

[28] V. Chaurasia and S. Pal (2014). Machine learning Approach to Detect Heart Diseases. Int. J. Adv. Comput. Sci. Inf. Technol. Vol. 2, no. 4, pp. 56–66, 2014.

[29] Omar Karam, Mostafa A. Salama and Randa El Bialy (2016). An ensemble model for Heart disease data sets : a generalized model. ACM, pp. 191–196, 2016.

[30] Arabasadi Z, Alizadehsani R, Roshanzamir M, Moosaei H, and Yarifard AA (2017). Computer-Aided Decision Making For Heart Disease Detection Using Hybrid Neural NetworkGenetic Algorithm. Computer Methods and Programs in Biomedicine 141 (2017) 19-26. https://doi.org/10.1016/j.cmpb.2017.01.004

[31] Geurts. Pierre, Ernst. Damien and Wehenkel. Louis (2006). Extremely Randomized Trees. Machine Learn 63: 3-42. DOI 10.1007/s10994-006-6226-1

[32] Natekin. Alexey and Knoll. Alois (2013). Gradient Boosting Machines-A Tutorial. Frontiers in Neuro Robotics Volume7| Article21.

[33] Biau Gerard (2012). Analysis of a Random Forests Model. Journal of Machine Learning Research 1063-1095.

[34] Khaing T. Kyaw (2010). Enhanced Features Ranking and Selection using Recursive Feature Elimination (RFE) and K- Nearest Neighbor Algorithms in Support Vector Machine for Intrusion Detection System. International Journal of Network and Mobile Technologies VOL 1/ ISSUE1/ JUNE.

[35] Chen. Tianqi and Guestrin. Carlos (2016). XG BOOST: A Scalable Tree Boosting System. KDD"16 Proceedings of the 22nd ACM SIGKDD International Conference on Knowledge Discovery and Machine learning Pages 785-794 at San Francisco, California, USA.

[36] Matkovsky, I., and Nauta, K. (1998). Overview of machine learning techniques. Presented at the Federal Database Colloquium and Exposition, San Diego, CA.

[37] Richard J. Roiger (2017). Machine learning: A Tutorial - Based Primer (Second Edition). CRC Press Taylor & Francis Group New York.

[38] Jure Leskovec, Anand Rajaraman, and Jeffrey Ullman (2014). Mining of Massive Datasets (Second Edition). Cambridge University Press. ISBN-10: 1107077230.

[39] Esposito, F., Malerba, D., Semeraro, G., and Kay, J. (1997). A comparative analysis of methods for pruning decision trees. IEEE Transactions on Pattern Analysis and Machine Intelligence, 19(5), 476-491.

[40] I.Ketut Agung Enriko, Muhammad Suryanegara, and Dadang Gunawan (2018). Heart Disease Diagnosis System with k-Nearest Neighbors Method Using Real Clinical Medical Records. Published in: Proceeding ICFET '18 Proceedings of the 4th International Conference on Frontiers of Educational Technologies Pages 127-131.

[41] Purnami, S., Zain, J., and Embong, A. (2010). A New Expert System for Diabetes Disease Diagnosis Using Modified Spline Smooth Support Vector Machine. Computational Science and Its Applications – ICCSA 2010 (Vol. 6019, pp. 83-92): Springer Berlin Heidelberg.

[42] Abdullah, A. S., and Rajalaxmi, R. R. (2012). A Machine learning Model for Predicting The Coronary Heart Disease using Random Forest Classifier. IJCA Proceedings on International Conference on Recent Trends in Computational Methods, Communication, and Controls (ICON3C 2012), ICON3C (3), 22-25.

[43] Mudasir M Kirmani and Syed Immamul Ansarullah (2016) Classification models on cardiovascular disease detection using Neural Networks, Naive Bayes and J48 Machine learning Techniques". International Journal of Advanced Research in Computer Science. Volume 7, No. 5, September-October 2016.

[44] Rajul Parikh, Annie Mathai, Shefali Parikh, G Chandra Sekhar and Ravi Thomas (2008). Understanding and using Sensitivity, Specificity, and Predictive Values. Indian Journal of Ophthalmology, Jan- Feb; 56(1): 45-50.

[45] Sonam Nikhar, A.M. Karandikar (2016) "Prediction of Heart Disease Using Machine Learning Algorithms" in International Journal of Advanced Engineering, Management and Science (IJAEMS)

[46] Deeanna Kelley "Heart Disease: Causes, Prevention, and Current Research" in JCCC Honors Journal.

[47] Ponrathi Athilingam, Bradlee Jenkins, Marcia Johansson, Miguel Labrador (2017) "A Mobile Health Intervention to Improve Self-Care in Patients With Heart Failure: Pilot Randomized Control Trial" in JMIR Cardio.

[48] DhafarHamed, Jwan K. Alwan, Mohamed Ibrahim, Mohammad B. Naeem (2017) "The Utilisation of Machine Learning Approaches for Medical Data Classification" in Annual Conference on New Trends in Information & Communications Technology Applications.

[49] Mai Shouman, Tim Turner, and Rob Stocker (2013) Applying kNearest Neighbour in Diagnosing Heart Disease Patients International Journal of Information and Education Technology, Vol. 2,

[50] Joo, G.; Song, Y.; Im, H.; Park, J. (2020) Clinical Implication of Machine Learning in Predicting the Occurrence of Cardiovascular Disease Using Big Data (Nationwide Cohort Data in Korea). IEEE Access, 8, 157643–157653.

[51] Amudhavel, J., Inbavalli, P., Bhuvaneswari, B., Anandaraj, B., Vengattaraman, T., Premkumar, K., (2015) "An effective analysis on

harmony search optimization approaches", International Journal of Applied Engineering Research, 10 (3), pp. 2035-2038.

[52] Modepalli, K.; Gnaneswar, G.; Dinesh, R.; Sai, Y.R.; Suraj, R.S. (2021) Heart Disease Prediction using Hybrid machine Learning Model. In Proceedings of the 2021 6th International Conference on Inventive Computation Technologies (ICICT), Coimbatore, India, 20– 22 January .

[53] Li, J.; Haq, A.; Din, S.; Khan, J.; Khan, A.; Saboor, (2020) 0A. Heart Disease Identification Method Using Machine Learning Classification in E-Healthcare. IEEE Access , 8, 107562–107582.

[54] Ali, F.; El-Sappagh, S.; Islam, S.M.R.; Kwak, D.; Ali, A.; Imran, M.; Kwak, K. (2020) A smart healthcare monitoring system for heart disease prediction based on ensemble deep learning and feature fusion. Inf. Fusion

[55] Rahim, A.; Rasheed, Y.; Azam, F.; Anwar, M.; Rahim, M.; Muzaffar, A. (2021) An Integrated Machine Learning Framework for Effective Prediction of Cardiovascular Diseases. IEEE Access

[56] Ishaq, A.; Sadiq, S.; Umer, M.; Ullah, S.; Mirjalili, S.; Rupapara, V.; Nappi, M. (2021) Improving the Prediction of Heart Failure Patients' Survival Using SMOTE and Effective Machine learning Techniques. IEEE Access

[57] Khurana, P.; Sharma, S.; Goyal, (2021) A. Heart Disease Diagnosis: Performance Evaluation of Supervised Machine Learning and Feature Selection Techniques. In Proceedings of the 8th International Conference on Signal Processing and Integrated Networks, SPIN 2021, Matsue, Japan

[58] Amudhavel, J., Padmapriya, S., Nandhini, R., Kavipriya, G., Dhavachelvan, P., Venkatachalapathy, V.S.K., (2016) "Recursive ant colony optimization routing in wireless mesh network", Advances in Intelligent Systems and Computing, 381, pp. 341-351.

[59] Nabil Alshurafa, Costas Sideris, Mohammad Pourhomayoun, Haik Kalantarian, Majid Sarrafzadeh (2015) "Remote Health Monitoring Out-come Success Prediction using Baseline and First Month Intervention Data" in IEEE Journal of Biomedical and Health Informatics

[60] Samineni, Peddakrishna. (2023). Enhancing Heart Disease Prediction Accuracy through Machine Learning Techniques and Optimization. Processes, doi: 10.3390/pr11041210

[61] Mohammed, Ali, Shaik., T., V., Akshay. (2023). Improving Accuracy of Heart Disease Prediction through Machine Learning Algorithms. doi: 10.1109/ICIDCA56705.2023.10100244

[62] Raniya, Rone, Sarra., Ahmed, Musa, Dinar., Mazin, Abed, Mohammed. (2022). Enhanced accuracy for heart disease prediction using artificial neural network. Indonesian Journal of Electrical Engineering and Computer Science, doi: 10.11591/ijeecs.v29.i1.pp375-38

[63] Dengqing, Zhang., Yunyi, Chen., Yuxuan, Chen., Shengyi, Ye., Wenyu, Cai., Junxue, Jiang., Yechuan, Xu., Gongfeng, Zheng., Ming, Chen. (2021). Heart Disease Prediction Based on the Embedded Feature Selection Method and Deep Neural Network.. Journal of Healthcare Engineering, doi: 10.1155/2021/626002

# Virtual Reality in Training: A Case Study on Investigating Immersive Training for Prisoners

Abdulaziz Alshaer

Dept. Computer Science, Jamoum University College, Umm Al-Qura University, Makkah, Saudi Arabia

*Abstract*—**This study addresses the pressing issue of prison rehabilitation by comparing traditional and Virtual Reality (VR) based training services offered by the General Directorate of Prisons in Saudi Arabia. Utilising Technology Acceptance Model (TAM) metrics such as perceived usefulness, ease of use, and enjoyment, the study evaluates the acceptance of VR technologies across two different headset platforms. Findings reveal that VR-based training services received significantly higher acceptance ratings than traditional methods. Both VR platforms were highly rated in terms of perceived usefulness, ease of use, and enjoyment but showed no significant differences between the headsets. These results indicate that VR-based methods could be more effective, engaging, and safer alternatives in correctional rehabilitation programs. Importantly, this research contributes to the field of Human-Computer Interaction (HCI) by suggesting design frameworks tailored for effective interventions in training and rehabilitative contexts where safety and psychological health are of high concern.**

*Keywords*—*Component; virtual reality; correctional services; technology acceptance; rehabilitation*

## I. INTRODUCTION

Prison rehabilitation has been a growing concern in recent years, as the recidivism rate remains high and the need for effective rehabilitation programs continues to grow. There are more than 60 thousand prisoners in Saudi Arabia [1] and more than 11 million globally [2]. Prisoners are a vulnerable group with mental disorders and infectious diseases compared to the general population [3]. They may show reluctance or lack interest in rehabilitation services and programs. In addition, the reluctance and lack of interest may result from the lack of interest in the traditional methods often used in prisons, including old, ineffective motivation techniques for rehabilitation.

In Saudi Arabia, prisoners are offered numerous rehabilitation services by Trahum (The National Committee for the Welfare of Prisoners and Released Prisoners and their Families in Saudi Arabia). Due to limited resources, safety, and individual mental status, not all services can be offered to them. Many prisoners struggle with substance abuse, mental health problems, and trauma, which can interfere with their rehabilitation and reintegration into society [4]. Nellis [5] added that the prison environment could be detrimental to rehabilitation efforts, with overcrowding, violence, and poor living conditions affecting prisoners' physical and psychological health.

Recently, interest in using VR technology in prisons has grown as a potential way to improve the outcomes of prisoner rehabilitation. VR technology can place users in safe learning environments by immersing them in realistic, regulated environments. Prisoners can engage in various rehabilitative, educational, and training activities in a safe, controlled, and immersive setting using VR [6]. VR technology can improve the delivery of social problem-solving treatment and successfully enhance psychological disorders [7]. Studies have investigated the use of VR in forensic mental health treatment [8]. According to a systematic review, VR can be utilised as a tool for assessment and treatment in forensic psychiatric settings. Exposure therapy, for example, is one potential application.

In addition, VR is an effective tool for teaching coping skills to users with disabilities [9]. In this study, participants with disabilities were trained in coping skills through VR simulations, and the results showed improved coping skills and increased self-efficacy. VR simulations can provide job training, cognitive behavioural therapy, and exposure therapy for Field individuals with mental health conditions [10]. VR can also address substance abuse and other high-risk behaviours through guided simulations that allow prisoners to experience the consequences of their actions [11]. VR technology in prisons has been shown to impact prisoners' well-being positively, behavioural change, and overall rehabilitation outcomes [11], [12].

VR has been used for crime prevention and rehabilitation [13]. In this study, the author explores the potential of VR as a rehabilitation tool to reduce recidivism and promote pro-social behaviour in criminal justice settings. According to a systematic review by [14], VR has shown potential as a tool for addressing various issues in criminal justice and rehabilitation, including anxiety disorders, post-traumatic stress disorder (PTSD), and teaching coping skills to people with disabilities. However, implementing and using VR in prisons requires careful consideration of ethics, security, and inmate acceptance.

VR acceptance depends on several factors, including perceived ease of use, usefulness, and enjoyment. Perceived ease of use refers to the ease with which a user can learn and use VR technology. In contrast, perceived usefulness refers to the extent to which VR technology is perceived as helpful and valuable [15]. Perceived enjoyment refers to the extent to which VR technology is experienced as a fun and enjoyable experience [16]. These three factors positively affect user adoption and acceptance of VR technology, and they are more likely to engage with and benefit from rehabilitation programs.

This study evaluates prisoners' acceptance of VR-based rehabilitation systems as an alternative to traditional methods. By leveraging the Technology Acceptance Model [15], it seeks to assess the perceived ease of use, usefulness, and enjoyment of VR in rehabilitation settings for two VR headsets. Our study's findings could have far-reaching implications for policymaking and prison management strategies, revolutionising how we approach rehabilitation and reintegration of prisoners into society. We hypothesised that 1) VR-based training and rehabilitation have a higher level of perceived ease of use, 2) VR-based training and rehabilitation have a higher level of usefulness, 3) VR-based training and rehabilitation have a higher level of enjoyment, and 4) VR-based training and rehabilitation have a higher level of prisoner acceptance compared to traditional training and rehabilitation services.

Following the introduction, Section II will delve into the 'Material and Methods' used in the research, providing insight into the study's methodology and data collection procedures. Section III will then present the findings of our study, followed by Section IV which deals with 'Discussion,' where the result is analysed and interpreted in the context of existing literature. Finally, the paper concludes in Section V by outlining potential directions for future work.

## II. MATERIAL AND METHODS

### A. Participants

The study comprised a group of 46 male inmates from Makkah prison in coordination with Tarahm. The age range of the participants was 18 to 41 years, with an average age of 23. Most participants were either single or divorced. Educational levels varied among the participants: three had completed primary education, eight had intermediate education, 28 had graduated high school, and few held university degrees. All participants were unemployed. On average, the duration of their incarceration was 3.6 years. The following figure shows the experiment setup (see Fig. 1).



Fig. 1. Experiment setup where prisoners take turns to participate.

In preparation for the forthcoming experiments, participants were asked to evaluate their computer skills, experience, and weekly usage of computers using a rating scale ranging from 1 to 5, with 5 indicating the highest level of proficiency. The outcomes of this assessment were as follows: Participants provided an average rating of 3.04 out of 5 for their computer skills, indicating a moderate level of competence. Regarding weekly computer usage, participants demonstrated an average

rating of 2.66 out of 5, suggesting a moderate frequency of interaction with computers. Moreover, participants show a notable interest in computer games, as evidenced by an average rating of 3.68 out of 5 for their level of engagement. Importantly, it's noteworthy that none of the participants had prior exposure to VR tools. These initial assessments aimed to provide insights into participants' familiarity with computer-related activities, informing their readiness to interact with the VR system during the experimental sessions.

### B. Apparatus

In this study, both software and hardware components were integrated. Through deliberations with the prison administration, a consensus emerged on employing a VR scenario that centred around mechanical training. Consequently, a VR environment was built, specifically designed for engine assembly. Within this immersive setting, participants were tasked with reassembling engine components, employing a VR controller as their interface. To facilitate this process, the system provided visual cues in the form of distinct colours, strategically guiding participants on the appropriate sequence of assembly steps (see Fig. 2)

In terms of hardware, the computational demands were adeptly met by an HP OMEN Gaming Laptop to power the VR headsets. For the immersive experience, two headsets were selected: the HTC Vive and the Oculus Rift. These cutting-edge devices were chosen to deliver a level of visual fidelity and interactivity, thus enhancing the realism and engagement of the participants within the virtual environment.
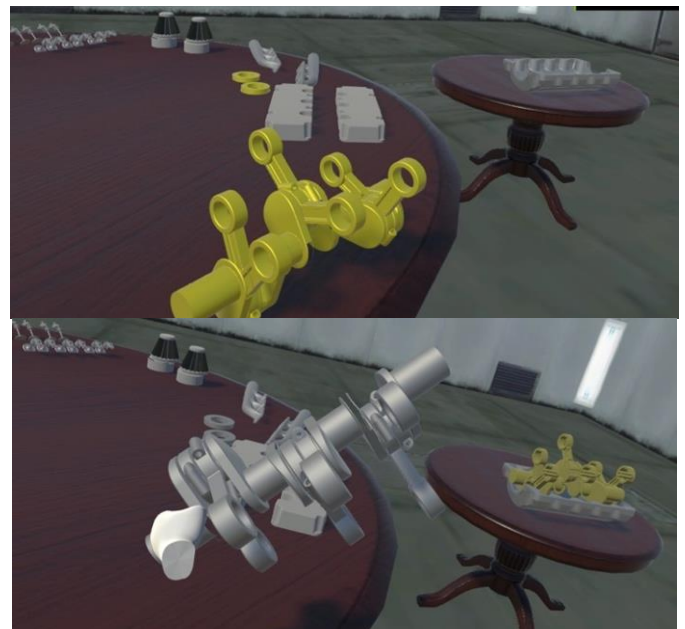


Fig. 2. The top picture shows the engine components to be installed next. The bottom picture shows picked-up components to be placed on the engine base.

### C. Data Collection

The research methodology entails the employment of a structured questionnaire as the primary data collection tool. This method uses various dimensions such as demographic information, proficiency in general skills, computer aptitude,

the acceptance model comprising perceived ease of use, perceived usefulness, and perceived enjoyment, along with an evaluation of preference. Additionally, insights into the utilisation of traditional rehabilitation services offered by Tarahm were obtained. The data amassed through the questionnaire was analysed through the Statistical Package for the Social Sciences (SPSS) software.

### D. Design and Procedure

In a within-subject experiment design, each participant was asked to perform the same task in each of the headsets (HTC Vive and the Oculus Rift) in a randomised and counterbalanced order, where across all participants, each headset was exactly 23 times the first and second. The task was to reassemble the whole engine.

Upon arrival, participants were welcomed and asked to sit down comfortably. After the introduction and provided written consent, participants were asked to complete a general demographic questionnaire. The information provided in the demographic questionnaire was then used to educate participants about using the headset and controllers. The participant started with a training session to get used to using the headset, followed by the actual experiment conditions. After each condition, participants were asked to complete a post-condition questionnaire. A self-report sheet was filled out by the researcher while the participant performed all three conditions. The report was then finished with the participants' verbal feedback gathered at the end of the experiment to help with future studies. The experiment was concluded by asking the participants to complete a preference questionnaire, and the participant was thanked for their participation.

### III. RESULTS

### A. Services Provided by the Prison and Tarahm

The prisoner receives their education and training from either the correctional service department in the prison or a third-party institution (Tarahm). This study compares the services provided by those two to compare that later to our proposed VR-based training. Three questions were asked for both as follows: 1) How do you evaluate the correctional services provided to you by the Prisons/Tarahm in general? 2) How do you evaluate the practical educational and training services provided to you by the Prisons/Tarahm? and 3) How is your interest in the educational and training services provided to you by the Prisons/Tarahm? The results of these metrics offer a general idea of how well these services are perceived, as well as their variability among the respondents. The following graphs represent subjects' responses to questions 1, 2, and 3 (see Fig. 3).
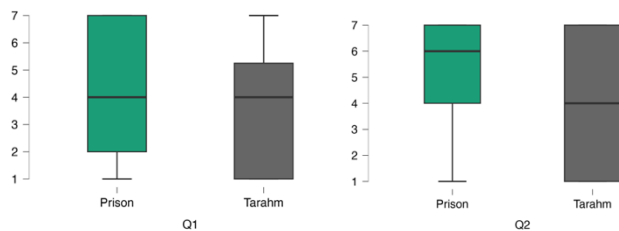




Fig. 3. Boxplots of all 3 questions: Q1: general service, Q2: training and education service, Q3: interest.

The means and standard deviation are reported in Table I. For the Evaluation of Correctional Services in General, the higher mean for the Prison (4.304) compared to Tarahm (3.722) suggests that, on average, respondents evaluate the services provided by the General Directorate of Prisons more favourably. There was no significant difference between the two groups .A paired-sample t-test revealed a t-statistic of 1.127, with df=45 ($p < .263$). The effect size was small, with a Cohen's d of 0.251.

Regarding the Evaluation of Practical Educational and Training Services, the Prison services (5.043) scored higher on average than Tarahm (4.083), indicating a preference for the educational and training services offered by the Prisons. There was no significant difference between the two groups .A paired-sample t-test revealed a t-statistic of 1.739, with df=45 ($p < .086$). The Cohen's d value of 0.387 suggests a small-to-medium effect size.

Prisoners' interest in Educational and Training Services shows similar results. The mean score for the Prison (4.696) is higher than for Tarahm (4.111), indicating that respondents are generally more interested in the educational and training services provided by the Prison. There was no significant difference between the two groups .A paired-sample t-test revealed a t-statistic of 1.041, with df=45 ($p < .301$). The Cohen's d value of 0.232 indicates a small effect size.

TABLE I. MEANS AND STANDARD DEVIATION FOR THE SERVICES PROVIDED BY THE PRISON AND TARAHM

| | Q1 | | Q2 | | Q3 | |
|---|---|---|---|---|---|---|
| | Prison | Tarahm | Prison | Tarahm | Prison | Tarahm |
| **Mean** | 4.304 | 3.722 | 5.043 | 4.083 | 4.696 | 4.111 |
| **SD** | 2.346 | 2.288 | 2.394 | 2.590 | 2.439 | 2.627 |

### B. Perceived Usefulness

Certainly, in the realm of Human-Computer Interaction (HCI), the perceived usefulness of a technology is a critical factor in its adoption and sustained usage [15]. Our study sought to assess the perceived usefulness of two prominent VR platforms, HTC Vive and Oculus, across three dimensions: general benefit (Using VR technology is good for me), efficiency and effectiveness (The use of VR technology makes me more efficient and effective), and ease of life (Using VR technology makes my life easier).

Employing a paired samples t-test, no statistically significant differences were found between the two platforms

for all three dimensions (p-values ranging from 0.816 to 0.897), as reported in Table II. The effect sizes, represented by Cohen's d, were negligible, ranging from 0.019 to 0.035, suggesting that any observed differences are not meaningful.

Participants consistently rated both platforms highly, with mean values ranging from 6.298 to 6.596 on a seven-point scale and standard deviations between 1.228 and 1.841. This suggests a strong and consistent perception among participants that both HTC Vive and Oculus are beneficial, efficient, and make life easier. Moreover, the uniformly high perception of usefulness across platforms provides strong empirical support for the integration of VR technologies in educational and training contexts.

TABLE II. PAIRED SAMPLE T-TEST FOR PERCEIVED USEFULNESS QUESTIONS

| Oculus | HTC Vive | t | df | p | Cohen's d | SE Cohen's d |
|---|---|---|---|---|---|---|
| Q1 | - Q1 | 0.130 | 45 | 0.897 | 0.019 | 0.219 |
| Q2 | - Q2 | 0.218 | 45 | 0.828 | 0.032 | 0.220 |
| Q3 | - Q3 | 0.234 | 45 | 0.816 | 0.035 | 0.213 |

### C. Perceived Ease of Use

In extending the investigation into the user experience of VR platforms, perceived ease of use was analyzed, a construct known to be highly correlated with technology adoption and sustained use in Human-Computer Interaction (HCI) research [15]. Three questions, in the form of a seven- point scale, assessed ease of use: 1) Using VR technology is easy, 2) Learning to use VR technology is easy, and 3) It's easy to use VR technology to complete tasks. A paired samples t-test revealed no statistically significant differences between the two platforms across these questions, with p-values ranging from 0.613 to 0.799. Furthermore, the effect sizes, as calculated by Cohen's d, were minimal and ranged from -0.051 to 0.075 as shown in Table III.

The means for all questions were exceedingly high (ranging from 6.596 to 6.761 on a seven-point scale) and exhibited low standard deviations (ranging from 0.705 to 1.258). This suggests not only a high perceived ease of use for both platforms but also a consistency in this perception among respondents.

TABLE III. PAIRED SAMPLE T-TEST FOR PERCEIVED EASE OF USE QUESTIONS

| Oculus | HTC Vive | t | df | p | Cohen's d | SE Cohen's d |
|---|---|---|---|---|---|---|
| Q1 | - Q1 | 0.256 | 45 | 0.799 | 0.038 | 0.201 |
| Q2 | - Q2 | 0.509 | 45 | 0.613 | 0.075 | 0.207 |
| Q3 | - Q3 | -0.345 | 45 | 0.732 | -0.051 | 0.214 |

### D. Perceived Enjoyment

The perceived enjoyment of technology is increasingly recognized as a key variable affecting its adoption and

sustained use, particularly within immersive platforms [17], [18]. This experiment aimed to explore the perceived enjoyment of HTC Vive and Oculus across four different dimensions, encompassing aspects of fun, enjoyment, impressiveness, and willingness to use VR technology for services and rehabilitation programs. The questions are as follows: 1) Using VR technology is fun, 2) Using VR technology is enjoyable, 3) Using VR technology is impressive, and 4) I am ready to use VR to benefit from the services program offered by the prison.

A paired samples t-test revealed that the perceived enjoyment does not significantly differ between the two platforms, ranging from 0.581 to 0.914. The effect sizes were marginal, with Cohen's d ranging from 0.016 to 0.082, indicating that any observed differences are practically insignificant, as shown in Table IV.

The mean scores for all the questions were remarkably high, ranging from 6.435 to 6.804 on a 7-point scale, with relatively low standard deviations (0.886 to 1.628). The consistency in these scores across dimensions and platforms suggests a high level of perceived enjoyment for VR technologies, regardless of the specific hardware.

TABLE IV. PAIRED SAMPLE T-TEST FOR PERCEIVED ENJOYMENT QUESTIONS

| Oculus | HTC Vive | t | df | p | Cohen's d | SE Cohen's d |
|---|---|---|---|---|---|---|
| Q1 | - Q1 | 0.139 | 45 | 0.890 | 0.020 | 0.218 |
| Q3 | - Q3 | 0.556 | 45 | 0.581 | 0.082 | 0.219 |
| Q4 | - Q4 | 0.187 | 45 | 0.853 | 0.028 | 0.219 |
| Q5 | - Q5 | 0.109 | 45 | 0.914 | 0.016 | 0.211 |

### E. Hardware Preference

Understanding users' preferences towards different VR headsets is pivotal in the HCI domain, particularly for tailoring experiences that are both engaging and comfortable [19], [20]. To this end, participants' preferences were evaluated based on four dimensions: comfort, presence, dizziness, and visual perception in the virtual world. Paired samples t-test indicated that there are no statistically significant differences in users' preferences between HTC Vive and Oculus for these dimensions, with p-values ranging from 0.587 to 0.916. This is corroborated by minimal effect sizes, where Cohen's d values varied between -0.081 and 0.069. See Table V for more details.

TABLE V. PAIRED SAMPLE T-TEST FOR PREFERENCE QUESTIONS

| Oculus | HTC Vive | t | df | p | Cohen's d | SE Cohen's d |
|---|---|---|---|---|---|---|
| Q1 | - Q1 | -0.548 | 45 | 0.587 | -0.081 | 0.222 |
| Q2 | - Q2 | 0.467 | 45 | 0.643 | 0.069 | 0.218 |
| Q3 | - Q3 | 0.106 | 45 | 0.916 | 0.016 | 0.226 |
| Q4 | - Q4 | -0.183 | 45 | 0.856 | -0.027 | 0.224 |

The descriptive statistics provided additional insights into the subjective experiences with the headsets. For instance, both

headsets scored high for comfort and presence (mean scores ranged from 6.213 to 6.426), suggesting that users generally felt comfortable and immersed while using VR. Interestingly, dizziness, a potential downside of VR experiences known as VR sickness [21], had a lower mean score (ranging from 3.298 to 3.596), which is a positive indication of the usability and acceptance of these platforms.

In sum, the data suggest that both HTC Vive and Oculus provide similarly positive experiences across multiple dimensions. As such, the choice between these two platforms may depend less on inherent qualities like comfort or immersion and more on other factors like cost, available software, or specific use cases, such as educational or therapeutic interventions.

### F. Comparison

Comparative analysis's most salient finding lies in the acceptance ratings, which represent a synthesis of perceived usefulness, ease of use, and enjoyment. The average acceptance rating for traditional services was 4.709 (SD = 2.148), significantly lower than the VR-based approach, with a mean rating of 6.601 (SD = 0.629). The paired samples t-test confirmed this difference as statistically significant (t = -5.516, df = 46, p < .001, Cohen's d = -0.805, SE = 0.259). Fig. 4 shows a graphical comparison between the two factors.

The stark disparity in ratings substantiates the compelling advantage of VR-based interventions over traditional methods in the context of correctional and rehabilitation services at the prison. the effect size is not just statistically significant but also practically meaningful.
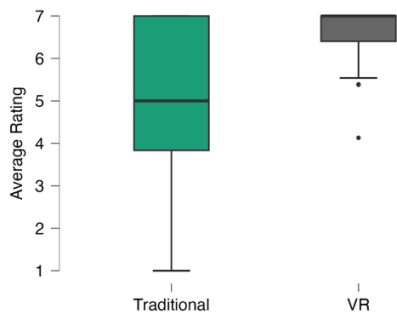


Fig. 4. Boxplots of participants' average rating for traditional services compared to VR-based training.

### IV. DISCUSSION

The integration of VR into various sectors, including training and rehabilitation, is gaining traction as a transformative technology. This study sought to evaluate and compare traditional methods of training and education by the Prisons and Tarahm, with a VR-based approach. Users' experiences were evaluated, comparing two major VR platforms, HTC Vive and Oculus, across several dimensions: perceived usefulness, perceived ease of use, perceived enjoyment, and headset preference.

Findings revealed that traditional services provided by the General Directorate of Prisons scored slightly better on average than those offered by Tarahm, though not to a level of statistical significance. This could be attributed to various factors such as service quality, accessibility, or even inmate familiarity with the correctional service department.

On the front of VR, data paints an optimistic picture of the perceived usefulness, perceived ease of use, and perceived enjoyment of using VR technology, regardless of the platform. Across all these dimensions, the scores were statistically indistinguishable between HTC Vive and Oculus. Interestingly, the perceived enjoyment scores were particularly high, aligning with extant literature that posits enjoyment as a crucial factor for the adoption and sustained use of technology [17], [18].

Importantly, both VR platforms scored highly on comfort and presence while scoring lower on inducing dizziness, a common VR issue. These findings imply that modern VR headsets have improved to the point where comfort and dizziness are less of a concern, thus potentially boosting their viability in applications like training and rehabilitation services. The lack of significant differences between the two platforms suggests that choices could be made based on other criteria, such as cost or specific features, rather than user experience [19], [20].

The VR-based approach demonstrated a significantly higher acceptance average rating when compared to traditional services. These results echo the comparative analysis presented in the results section and provide compelling evidence for VR's potential to be more favourably received than traditional methods and a safer option to adopt for prisoners. Findings support the notion that VR-based training could be an alternative to traditional correctional services in some cases or scenarios, given the high levels of perceived usefulness, ease of use, and enjoyment. Second, the platform-agnostic nature of these experiences points to the greater importance of content and application design in achieving successful outcomes. Third, for decision-makers in correctional services, it serves as a compelling argument for investment in VR technologies. Furthermore, it presents a new avenue for HCI researchers focused on rehabilitation and correctional technology, underscoring the need for a design framework that leverages VR's strengths in delivering effective interventions. Limitations of this study include the focused task scenario and the limited number of platforms evaluated.

### V. CONCLUSION AND FUTURE WORKS

This study represents a comprehensive evaluation of the role of VR technologies, specifically HTC Vive and Oculus, in comparison to traditional educational and training methods provided by prison facilities and third-party institution (Tarahm). It was found that while traditional services had no statistically significant advantages over one another, both HTC Vive and Oculus demonstrated exceptional performance in perceived usefulness, ease of use, and enjoyment among users.

Significantly, when comparing VR-based training to traditional methods, the VR-based approach exhibited considerably higher levels of user acceptance. This finding not only supports the potential of VR as a viable alternative but also presents compelling empirical evidence for its integration into training and rehabilitation services. Given that there was little to no difference in the perceived quality of experience between HTC Vive and Oculus.

These results serve as a roadmap for decision-makers in correctional services contemplating investment in VR technologies. They also highlight the necessity for further research in this area, especially for understanding long-term outcomes and expanding the number of platforms evaluated.

This study opens new doors for HCI researchers, particularly those focusing on technology design in training and rehabilitative contexts. It underscores the imperative to establish a design framework that exploits VR's unique strengths, leading to more effective interventions in training and education settings.

Future research should expand on these variables and consider long-term impacts and outcomes. For example, future studies could evaluate learning outcomes and extend to other fields of study, such as therapy. One potential area to investigate is the use of VR to allow participants to live situations outside the prison wall, for instance, visiting family or walking on a beach. This would serve as an adaptation method for prisoners before they are released into society.

### REFERENCES

[1] 'Ministry of Interior Annual Report 2020', Ministry of Interior, Kingdom of Saudi Arabia. Accessed: Feb. 07, 2023. [Online]. Available: https://www.moi.gov.sa/wps/portal/Home/Home/

[2] 'Saudi Arabia | World Prison Brief'. Accessed: Feb. 07, 2023. [Online]. Available: https://www.prisonstudies.org/country/saudi-arabia

[3] T. Hewson, A. Shepherd, J. Hard, and J. Shaw, 'Effects of the COVID-19 pandemic on the mental health of prisoners', Lancet Psychiatry, vol. 7, no. 7, pp. 568–570, Jul. 2020, doi: 10.1016/S2215-0366(20)30241-8.

[4] D. James and L. Glaze, 'Mental Health Problems of Prison', 2006.

[5] A. Nellis, 'The Color of Justice: Racial and Ethnic Disparity in State Prisons', Oct. 2021, Accessed: Feb. 07, 2023.

[6] Virtual Reality in Education: A Case Study on Exploring Immersive Learning for Prisoners | IEEE Conference Publication | IEEE Xplore'. Accessed: Aug. 28, 2023.

[7] T. J. D'Zurilla, A. M. Nezu, and A. Maydeu-Olivares, 'Social Problem Solving: Theory and Assessment', in Social problem solving: Theory, research, and training, Washington, DC, US: American Psychological Association, 2004, pp. 11–27. doi: 10.1037/10805-001.

[8] K. Sygel and M. Wallinius, 'Immersive Virtual Reality Simulation in Forensic Psychiatry and Adjacent Clinical Fields: A Review of Current Assessment and Treatment Methods for Practitioners', Frontiers in Psychiatry, vol. 12, 2021, Accessed: Feb. 07, 2023.

[9] A. Alshaer, 'Influence of peripheral and stereoscopic vision on driving performance in a power wheelchair simulator', University of Otago, 2012.

[10] G. Riva, 'Virtual Reality in Clinical Psychology', Comprehensive Clinical Psychology, pp. 91–105, 2022, d

[11] D. Taubin et al., 'A systematic review of virtual reality therapies for substance use disorders: Impact on secondary treatment outcomes', Am J Addict, vol. 32, no. 1, pp. 13–23, Jan. 2023, doi: 10.1111/ajad.13342.

[12] J. Blascovich and J. Bailenson, Infinite Reality: Avatars, Eternal Life, New Worlds, and the Dawn of the Virtual Revolution, Illustrated edition. William Morrow Paperbacks, 2011.

[13] B. Ticknor and S. Tillinghast, 'Virtual Reality and the Criminal Justice System: New Possibilities for Research, Training, and Rehabilitation', Journal of Virtual Worlds Research, vol. 4, p. 4, Jul. 2011, doi: 10.4101/jvwr.v4i2.2071.

[14] B. Ticknor, Virtual Reality and the Criminal Justice System: Exploring the Possibilities for Correctional Rehabilitation. Lexington Books, 2018.

[15] F. D. Davis, 'Perceived Usefulness, Perceived Ease of Use, and User Acceptance of Information Technology', MIS Quarterly, vol. 13, no. 3, pp. 319–340, 1989, doi: 10.2307/249008.

[16] V. Venkatesh and F. D. Davis, 'A Theoretical Extension of the Technology Acceptance Model: Four Longitudinal Field Studies', Management Science, vol. 46, no. 2, pp. 186–204, Feb. 2000, doi: 10.1287/mnsc.46.2.186.11926.

[17] M. Hassenzahl, 'The Thing and I: Understanding the Relationship Between User and Product', vol. 3, 2005, pp. 31–42. doi: 10.1007/1-4020-2967-5_4.

[18] V. Venkatesh, J. Y. L. Thong, and X. Xu, 'Consumer Acceptance and Use of Information Technology: Extending the Unified Theory of Acceptance and Use of Technology', MIS Quarterly, vol. 36, no. 1, pp. 157–178, 2012, doi: 10.2307/41410412.

[19] M. J. Schuemie, P. van der Straaten, M. Krijn, and C. A. van der Mast, 'Research on presence in virtual reality: a survey', Cyberpsychol Behav, vol. 4, no. 2, pp. 183–201, Apr. 2001, doi: 10.1089/109493101300117884.

[20] M. Slater and S. Wilbur, 'A Framework for Immersive Virtual Environments Five: Speculations on the Role of Presence in Virtual Environments', Presence: Teleoper. Virtual Environ., vol. 6, no. 6, pp. 603–616, Dec. 1997, doi: 10.1162/pres.1997.6.6.603.

[21] J. J. LaViola, 'A discussion of cybersickness in virtual environments', SIGCHI Bull., vol. 32, no. 1, pp. 47–56, Jan. 2000, doi: 10.1145/333329.333344.

# Benchmarking the LGBM, Random Forest, and XGBoost Models Based on Accuracy in Classifying Melon Leaf Disease

Chaerur Rozikin[1], Agus Buono[2], Sri Wahjuni[3], Chusnul Arif[4], Widodo[5]

Dept. Computer Science, IPB University, Bogor, Indonesia[1, 2, 3]

Dept. Informatics, University of Singaperbangsa, Karawang, Indonesia[1]

Dept. Civil and Environmental, IPB University, Bogor, Indonesia[4]

Dept. Plant Protection, IPB University, Bogor, Indonesia[5]

*Abstract*—Leaf diseases in melon plants cause losses for melon farmers. However, melon plants become less productive or even die. Downy mildew is a foliar disease that spreads rapidly in melon plants. Determining the level of downy mildew in melon leaves is important. Determining the level of downy mildew disease, farmers can carry out preventive treatment according to the severity level of downy mildew disease. This study aimed to create a classification model for the level of downy mildew disease on melon leaves using combined features and to compare the classification models, namely the LGBM, Random Forest, and XGBoost models. The combined features consist of colour, texture, Shannon entropy, and Canny edge features. The combined features are used as input for a classification model to predict the level of downy mildew leaf disease in melon plants. Model evaluation was carried out with three scenarios of data sharing: the first scenario, 90% training data and 10% test data; the second scenario, 80% training data and 20% test data; and the third scenario, 70% training data and 30% test data. The results of the evaluation of the model with the confusion matrix show that for the first and second scenarios, the highest accuracy was achieved by the Random Forest algorithm, with 72% and 73% accuracy, respectively. For the third scenario, the highest accuracy was obtained using the XGBoost algorithm.

*Keywords—Classification; Downy mildew; LGBM; disease level; melon leaves*

## I. INTRODUCTION

Melon is a fruit commodity with a high selling price, and many farmers cultivate it. Cultivating melons is difficult because there are many diseases associated with melon plants. Based on their causes, melon plant diseases are divided into three types: viruses, bacteria, and fungi [1]. One type of disease that infects the leaves is downy mildew. Downy mildew disease spreads very quickly, and if it is not controlled correctly, it can cause melon plants to die [2]. Determining the level of downy mildew disease on melon leaves is essential; this is done to determine the development of downy mildew disease that infects the leaves. In addition, by determining the level of downy mildew disease, farmers can carry out preventive treatments according to the level of development of downy mildew disease.

To overcome this problem, image processing (IP) and machine learning (ML) approaches can be used to classify the levels of downy mildew disease on melon leaves to help farmers treat downy mildew disease on melon leaves. IP and ML have been widely used to detect, identify, and classify leaf diseases [3]. This has been proven by many related scientific publications, including the classification of tomato leaf disease with public datasets using multiple feature extraction techniques, namely colour histograms, Hu Moments, Haralick and Local Binary Pattern features and classification models using Random Forest and decision tree classification; model evaluation results in decision tree classification with 90% accuracy and 94% Random Forest model [4]. Classification of banana leaf disease into four disease classes: healthy leaves, Sigatoka-infected leaves, Pestalotiopsis infected leaves, and Cordana-infected leaves using DenseNet and Inception. The result is that the model using the DenseNet method with an oversampling scheme is superior, with an accuracy of 84.73% [5]. Classification of grape leaf disease into two classes, namely healthy leaves and leaf spot (Cercospora), using Deep Forest, the evaluation results showed an accuracy of 96.25% [6]. Segmentation of cucumber leaf disease to detect cucumber leaf disease points using an improved saliency method and deep feature selection with an accuracy of 97.23% [7]. To detect and classify leaf diseases, feature extraction is required, and the feature extraction results are used as a dataset for classification [8]. In general, the feature extraction used by researchers is colour, texture, shape, and edge features [9]. The feature extraction results are then classified using a classification algorithm. Currently, many leaf disease classification algorithms have been developed, including SVM, Naive Bayes, Decision Tree, KNN, Random Forest, AdaBoost, Neural Network, Rule Base Classifier, Fuzzy Classifier [10] [11].

Classification of the severity of tea leaf blight using deep learning methods such as VGG16 deep networks is an interesting application in the fields of agriculture and pest management. In this case, the tea leaf blight was divided into two levels: mild and severe. The test results of the proposed model had an average accuracy of 84.5%, which was considered a good result [12]. To classify the severity of leaf diseases in tomato plants, deep learning using the ResNet architecture was used. This classification differentiates tomato leaves into three categories: healthy leaves, leaves affected by mild diseases, and leaves affected by severe diseases. The test

results of this model showed an average accuracy of 88.2% [13]. To classify the severity of bacterial leaf streak leaf disease in rice plants, deep learning with BLSNet architecture was used. This classification divides the severity of the disease into five levels: level 0, leaves with no lesions; level 1, lesions less than 10%; level 2: Lesions 11-25%, level 3: Lesions 26-45%, level 4: Lesions 46-65%, and level 5, lesions > 65%. The BLSNet model test results showed an average accuracy of 98.2% [14].

A melon leaf image dataset was collected from a farmer's garden under natural conditions. Furthermore, the dataset is extracted for colour features by calculating the average colour value, standard deviation, skewness, texture, Shannon entropy, Canny edge, and colour histogram. Extraction of GLCM texture features with distances of 1, 3, and 5 and angles of $0^0$, $45^0$, $90^0$, and $135^0$ to obtain homogeneity, entropy, energy, contrast, and correlation values. Shannon entropy feature extraction is a feature extraction method used to obtain the value of the information acquisition between classes. Edge feature extraction values were obtained using Canny Edge.

The results of feature extraction were then combined into combined features. The combined features are used as inputs for the LGBM, Random Forest and XGBoost classification models. The model was evaluated using a confusion matrix and a scenario of dividing the training data and test data into three scenarios: 90% training data and 10% test data, 80% training data and 20% test data, and 70% training data and 30% test data. A confusion matrix was used to determine the best model for predicting the level of downy mildew disease in melon leaves.

The purpose of this study was to create a classification model for the levels of downy mildew disease on melon leaves, namely healthy leaves (DS), downy mildew level 1 (DM1), downy mildew level 2 (DM2), and downy mildew level 3 (DM3), using a combination of texture, colour, entropy Shannon, and edge features. The second was to compare the classification models, namely, LGBM, Random Forest, and XGBoost.

## II. RESEARCH METHOD

A melon leaf image dataset was collected from a farmer's garden under natural conditions. Furthermore, the dataset is extracted for colour. This study has several stages; namely, data collection, pre-processing, feature extraction, classification, and evaluation of the model created using the confusion matrix (see Fig. 1).

### A. Data Acquistion

Melon was planted from 17 October 2022 to 20 December 2022. The planting site was in Sukatani village, Sukatani sub-district, Purwakarta district, West Java. Melon plants were planted with as many as 30 plants, and for each melon plant, a sample of five leaves was selected randomly and then marked to differentiate. After 26 days after planting (HST), pictures of melon leaves were taken every two days from 11 November 2022 to 15 December 2022. Using a smartphone camera, smartphone specifications are shown in Table I.
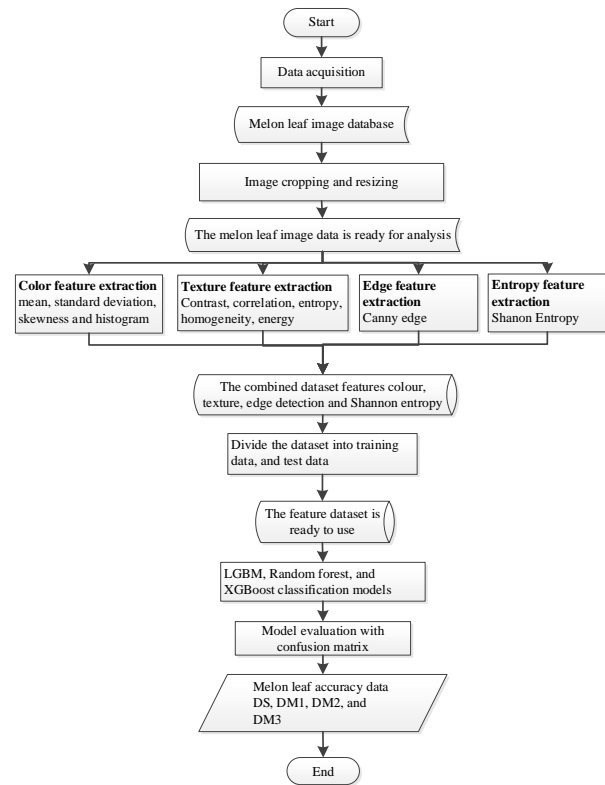


Fig. 1. Research stages.

TABLE I. SMARTPHONE SPECIFICATIONS

| No | Name | Description |
|---|---|---|
| 1 | Smartphone | Infinix Note 11 NFC |
| 2 | Camera resolution | 50 MP, f/1.6, (wide), PDAF, 2 MP, f/2.4, (depth) |
| 3 | Operating system | Android 11 |

When photographing melon leaves, it is necessary to consider technical factors. The technical factors considered are listed in Table II.

TABLE II. PHOTOGRAPHING TECHNIQUE

| No | Parameter (variabel konfirmasi) | Description |
|---|---|---|
| 1 | Shooting frequency | Once every two days |
| 2 | The distance between the leaf object and the camera | 20 cm and 30 cm centred on the leaf object, and the leaf object does not exceed the camera frame |
| 3 | Angle position between camera and object (leaf) | Centered on the leaf object |
| 4 | Position between camera frame and object (leaf) | The leaf object is centred and does not exceed the smartphone camera frame. |

### B. Melon Leaf Image Dataset

The melon leaf data collected for a total of 1861 images were then labelled with the grading of melon leaf downy mildew disease. The labelling process involves a plant protection lab to determine the grading of downy mildew. The labelling process included healthy leaf labels (DS), downy mildew level 1 (DM1), downy mildew level 2 (DM2), and downy mildew level 3 (DM3). Table III shows the number of images from the DS, DM1, DM2, and DM3.

TABLE III.     DETAILS THE AMOUNT OF DATA

| No | Level of disease severity | Amount of data |
|---|---|---|
| 1 | Healthy Leaves (DS) | 665 images |
| 2 | Downy Mildew level 1 (DM1) | 449 images |
| 3 | Downy Mildew level 2 (DM2) | 253 images |
| 4 | Downy Mildew level 3 (DM3) | 494 images |
| Total amount of data | | 1861 images |

Labelled downy mildew level 1 begins to show signs of disease until it spreads 20% on leaves, labelled downy mildew level 2, downy mildew disease begins to spread 20% - 30% on leaves, and downy mildew level 3 on melon leaves is more than 30% level of leaf disease. Fig. 2 shows (a) DS, (b) DM1, (c) DM2, and (d) DM3.



(a)                                        (b)

(c)                                        (d)
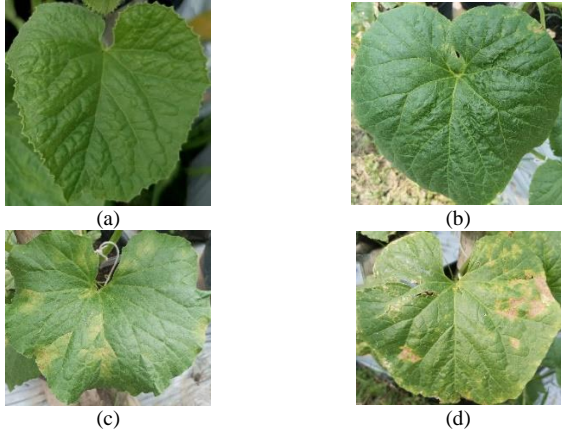
Fig. 2.   Examples of melon leaves (a) DS, (b) DM1, (c) DM2, and (d) DM3.

### C. Preprocess

Melon leaf image data were then preprocessed. The preprocessing involved cutting the image data and changing the size of the image data. Cutting the melon leaf image data aims to remove unwanted objects so that only melon leaf objects are produced. After cutting, the size was changed from the initial size of 2087 pixels × 2087 pixels to 128 pixels × 128 pixels. Changing the image data size aims to accelerate the computational process when performing feature extraction. Subsequent preprocessing changes the colour from RGB to grayscale.

### D. Colour, Texture, and Edge Feature Extraction Melon Leaf Image Database

After preprocessing, the feature extraction process was performed. Feature extraction is performed to obtain the value from the image. In this study, the feature extraction included colour, texture, and shape features. Feature extraction obtains the average colour value in Eq. (1), standard deviation in Eq. (2), and skewness in Eq. (3) [15].

$$\text{Mean} = \frac{1}{M \, X \, N}\sum_{X=1}^{M}\sum_{y=1}^{n}M_{xy} \qquad (1)$$

$$SD = \sqrt{\frac{1}{M \, X \, N}\sum_{x=1}^{M}\sum_{y=1}^{N}\left(M_{xy} - m\right)^2} \qquad (2)$$

$$Skewness = \frac{\sum_{x=1}^{M}\sum_{y=1}^{N}\left(M_{xy} - m\right)^3}{(M \, x \, N) \, x \, SD^3} \qquad (3)$$

The extracted colour feature values are blue mean, green average, red average, blue standard deviation, green standard deviation, red standard deviation, blue kurtosis, green kurtosis, red kurtosis, blue skewness, green skewness, and red skewness.

The subsequent colour feature extraction is a histogram obtained by extracting the histogram values using Eq. (4) [16].

$$h(r_k) = n_k \qquad (4)$$

where is $n_k$ the number of pixels with intensity level.

Texture feature extraction was carried out to obtain the distance and angle values by taking energy in Eq. (5), correlation values in Eq. (6), contrast in Eq. (7), entropy in Eq. (8), and homogeneity in Eq. (9) [4].

$$Energy = \sum_{i,j}(p(i,j))^2 \quad (5)$$

$$Correlation = \frac{\sum_i \sum_j (ij)P\,(i,j) - \mu_x\mu_y}{\sigma_x\sigma_y} \quad (6)$$

$$Cont = \sum_{n=0}^{N_g-1} N^2 \left\{\sum_{i=1}^{N_g}\sum_{j=1}^{N_g} P(i,j)\right\}, |i - j| = n \quad (2)$$

$$Entropy = -\sum_i \sum_j P(i,j)log\big(P(i,j)\big) \quad (8)$$

$$Homogeneity = \sum_{i,j}\frac{p(i,j)}{1+|i-j|} \quad (9)$$

The extracted GLCM feature values with variations of distance 1, 3, 5 and angles $0^0$, $45^0$, $90^0$, $135^0$.

The extracted edge feature value is Canny. The canny edge feature removes noise by using a Gaussian filter with the following Eq. (10) [17].

$$G(x.y) = \frac{1}{2\pi\sigma^2}exp\left(-\frac{x^2 + y^2}{2\sigma^2}\right) \qquad (10)$$

where $y$ is the distance from the origin on the vertical axis, $x$ is the distance from the origin on the horizontal axis, and σ is the standard deviation of the Gaussian distribution.

The next step is calculating the image gradient by calculating the gradient magnitude ($G$) and angle gradient ($\theta$) with the Eq. (11) and Eq. (12).

$$G = \sqrt{\left(G_x^2 + G_y^2\right)} \qquad (11)$$

$$\theta = tan\left(\frac{G_y}{G_x}\right) \qquad (12)$$

$G_x$ represents the horizontal and $G_y$ vertical gradients, respectively.

Shannon stated that the measure of the amount of information $H(p)$ contained in a series of events $p_1 \dots p_n$ must meet three conditions, namely, $H$ must be continuous in $p_i$, secondly if all $p_i$ have the same probability, so $p_i = \frac{1}{N}$, then $H$ should be a monotonic rising function of $N$, and $H$ must be additive [18]. Eq. (13) extracts Shannon entropy features.

$$H(p) = -k \sum_{i=1}^{N} p_i ln p_i \quad (13)$$

## E. Combined Feature Dataset

The results of colour, texture, edge, and entropy feature extraction were in the form of colour, texture, edge, and entropy feature datasets. DFColour denotes the colour feature dataset, DFTexture denotes the texture feature dataset, DFEdge denotes the edge feature dataset, and DFEntropy denotes the entropy feature dataset. Then, the combined feature dataset can be formulated using Eq. (14).

$$DFCombined = DFColour \cup DFTekstur \cup DFEdge \cup DFEntropy \quad (3)$$

where DFCombined is the combined feature dataset. The total DFCombined has as many as 838 features.

## F. Train Data, and Test Data

The DFCombined feature divides the data, namely, training data and test data. The scenarios for dividing the training and test data are shown in Table IV.

TABLE IV. DATA DIVIDING SCENARIO

| Scenario | Training Data % | Test Data % |
|---|---|---|
| 1 | 90 | 10 |
| 2 | 80 | 20 |
| 3 | 70 | 30 |

## G. LGBM Random Forest, XGBoost

Furthermore, the combined DF dataset will be classified for grading downy mildew using three classification models, namely LGBM, Random Forest and XGBoost, according to the scenario of dividing the training data and test data. The results will be compared based on the accuracy values of the three models.

## H. Evaluation of the Confusion Matrix Model

It is necessary to develop an evaluation model to measure the performance of the LGBM algorithm. The confusion matrix measures the performance of a classification algorithm by creating a detailed table of the amount of data that is classified correctly or incorrectly. The confusion matrix measures the accuracy, precision, recall, and F1 score [19]. The accuracy value is obtained from the amount of positive data predicted to be positive and the amount of harmful data predicted to be negative divided by the total amount of data, as shown in Eq. (15). The precision value is obtained from the number of opportunities for positive predictive data and the reality of the positive data, as shown in Eq. (16). The recall value is obtained from the number of positive data opportunities, and the prediction results are positive, as shown in Eq. (17). The F1 score was obtained from the recall and precision between the predicted and actual data as shown in Eq. (18).

$$Accuray = \frac{TP+TN}{TP+FP+FN+TN} \quad (15)$$

$$Precision = \frac{TP}{TP+FP} \quad (16)$$

$$Recall = \frac{TP}{TP+FN} \quad (17)$$

$$F1 = \frac{2 \; x \; Recall \; x \; Precision}{Recall+Precision} \quad (18)$$

Where TP = True Positive, FP = False Negative, TN = True Negative, FN = False Negative F1 = F-Measure.

## III. RESULTS AND DISCUSSIONS

The melon leaf disease image dataset consisted of healthy leaves (DS), downy mildew grade 1 (DM1), downy mildew grade 2 (DM2), and downy mildew grade 3 (DM3), which were divided into four classes: DS, DM1, DM2, and DM3.

## A. Preprocess

Melon leaf image data were preprocessed. Pre-processing involved cutting the image data and changing the size of the image data. Cutting the melon leaf image data aims to remove unwanted objects such that only melon leaf objects are produced. The original and cropped images are shown in Fig. 3(a) original image and Fig. 3(b).



(a) Original image      (b) Cropping image

Fig. 3. (a) Original image and (b) Cropping image.

After cutting, the size was changed from the initial size of 2087 pixels × 2087 pixels to 128 pixels × 128 pixels. Changing the image data size aims to speed up the computational process when performing feature extraction, and the subsequent preprocessing changes the colour from RGB to grayscale, as shown in Fig. 4(a) and Fig. 4(b).



(a) RGB image      (b) Grayscale image

Fig. 4. Image conversion (a) RGB color (b) grayscale.

## B. Feature Extraction

Colour feature extraction was performed to obtain the colour feature values. The extracted colour feature values are the average red, green, and blue colour values. Column Sample leaf number is sample of leaf, column meanR is the average value of red, Column meanG is the average value of green, and Column meanB is the average value of blue see Table V.

TABLE V. THE AVERAGE VALUE OF THE COLOURS R, G, AND B

| Sample leaf number | meanR | meanG | meanB |
|---|---|---|---|
| 1 | 130.8272 | 131.0041 | 130.8621 |
| 2 | 130.806 | 130.9863 | 130.8507 |
| 3 | 130.8316 | 131.0139 | 130.8828 |

Variants of colour features were extracted from red, green, and blue variances. Column Sample leaf number is sample of leaf, column VarianceR is the red variation value, column VarianceG is the green colour variation value, and column VarianceB is the green colour variation value (see Table VI).

TABLE VI.    VARIANCE VALUES R, G, AND B

| Sample leaf number | varianceR | varianceG | varianceB |
|---|---|---|---|
| 1 | 3373.02 | 3491.309 | 3611.722 |
| 2 | 3371.538 | 3489.867 | 3610.48 |
| 3 | 3371.666 | 3489.709 | 3610.031 |

Skewness values were extracted to obtain the red, green, and blue skewness values. Column Sample leaf number is sample of leaf, column SkewnessR is the red skewness value, column SkewnessG is the green skewness value, and column SkewnessB is the blue skewness value (see Table VII).

TABLE VII.    SKEWNESS VALUES R, G, AND B

| Sample leaf number | skewnessR | skewnessG | skewnessB |
|---|---|---|---|
| 1 | -0.06524 | -0.05881 | -0.04562 |
| 2 | -0.06546 | -0.05898 | -0.04581 |
| 3 | -0.06603 | -0.05949 | -0.04637 |

The results of the colour feature extraction obtained the feature values of the nine features.

Subsequent colour feature extraction uses a histogram. A histogram was used to determine the distribution of colours in the image. The histogram feature value was obtained by calculating the histogram value of each pixel in the image. The histogram feature extraction resulted in 512 histogram features.

The subsequent feature extraction is a texture feature using GLCM. The values extracted from the GLCM texture features were the energy, correlation, dissimilarity, homogeneity, and contrast. Variation in GLCM values at distances of 1, 3, 5 and angle variations, namely $0^0$, $45^0$, $90^0$, $135^0$. The following iteration 1 is used:

---
**Iteration 1**

```
distances = [1, 3, 5]
angles = [0, np.pi/4, np.pi/2, 3*np.pi/4]
        for d in distances:
            for a in angles:
                GLCM = graycomatrix(img, [d], [a])
                GLCM_Energy = graycoprops(GLCM,
                'energy')[0]
                df[f'Energy_d{d}_a{a}'] = GLCM_Energy
                GLCM_corr = graycoprops(GLCM,
                'correlation')[0]
                df[f'Corr_d{d}_a{a}'] = GLCM_corr
                GLCM_diss = graycoprops(GLCM,
                'dissimilarity')[0]
                df[f'Diss_sim_d{d}_a{a}'] = GLCM_diss
                GLCM_hom = graycoprops(GLCM,
                'homogeneity')[0]
                df[f'Homogen_d{d}_a{a}'] = GLCM_hom
                GLCM_contr = graycoprops(GLCM, contrast')[0]
                df[f'Contrast_d{d}_a{a}'] = GLCM_contr
```

Thus, the distance and angle texture features formed 60 texture features. Table VIII shows an example of the feature extraction results for a distance of 1 and an angle of $0^0$. Column Sample leaf number is sample of leaf, column Energy_d1_$0^0$ is the energy value, column Corr_d1_$0^0$ is the coorelation value, column Diss_sim_d1_$0^0$ is the dissimiliarity value, column Homogen_d1_$0^0$ is the homogeinity value, column Contrast_d1_$0^0$ is the contrast value.

TABLE VIII.    TEXTURE VALUE EXTRACTION

| Sample leaf Number | Energy_d1_$0^0$ | Corr_d1_$0^0$ | Diss_sim_d1_$0^0$ | Homogen_d1_$0^0$ | Contrast_d1_$0^0$ |
|---|---|---|---|---|---|
| 1 | 0.01236 | 0.85204 | 17.16683 | 0.08106 | 659.80450 |
| 2 | 0.01156 | 0.76719 | 22.35888 | 0.06753 | 1088.4191 |
| 3 | 0.01532 | 0.76395 | 15.14720 | 0.08373 | 504.07068 |

The entropy feature is used to make it easier to deal with uncertainty in classifying diseases into DS, DM1, DM2, and DM3 classes, so that the presence of entropy can increase the value of information between classes in the classification so that it can improve prediction results by measuring the highest information gain. The following is an example of the entropy shanon feature value. Column Sample leaf number is sample of leaf, column Entropy is the entropy value which is shown in Table IX.

TABLE IX.    EXTRACTION OF ENTROPY VALUES

| Sample leaf Number | Entropy |
|---|---|
| 1 | 7.542966 |
| 2 | 7.573822 |
| 3 | 7.020211 |

Edge feature extraction is used to determine points that experience a drastic change in brightness, typically in a line or curve, known as an edge. The edge feature values can be extracted using the Canny edge method [20]. The Canny edge feature extraction results are in the form of 256 features.

### C. The Combined Features

The extraction results of colour, texture, entropy, and Canny features yielded 521 colour features, 60 texture features, one entropy feature, and 256 Canny edge features. Then, these features are combined so that the total number of features extracted from feature extraction is 838.

### D. The Scenario of Dataset Division

After the combined features were obtained, they were used as datasets. The combined feature dataset was divided into training and test data for modelling. The scenario of dividing the dataset into training and test data was performed using three comparison scenarios for further details (see Table X).

TABLE X.        THREE SCENARIOS FOR DIVIDING DATA

| No | Level of disease severity | Total Data | Scenario 1 | | Scenario 2 | | Scenario 3 | |
|----|---------------------------|------------|-----|-----|-----|-----|-----|-----|
| | | | 90% | 10% | 80% | 20% | 70% | 30% |
| 1 | DS | 665 | 598 | 67 | 532 | 133 | 465 | 200 |
| 2 | DM1 | 449 | 404 | 45 | 359 | 90 | 314 | 135 |
| 3 | DM2 | 253 | 227 | 26 | 202 | 51 | 177 | 76 |
| 4 | DM3 | 494 | 444 | 50 | 404 | 99 | 345 | 149 |

*E. LGBM, Random Forest, and XGBoost Models*

*1) Scenario 1*: The dataset was divided into training and test data at a ratio of 90% training data and 10% test data. The classification results for LGBM, Random Forest, and XGBoost are shown in Fig. 5.
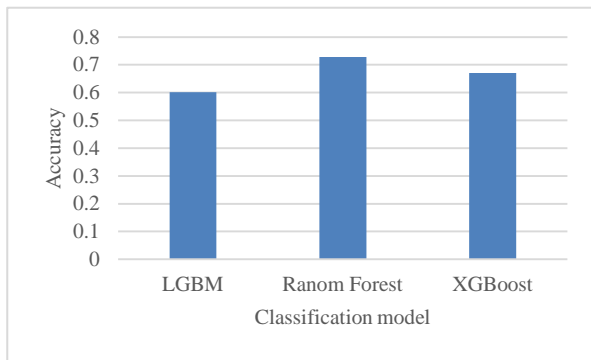


Fig. 5.    Accuracy with 90% training data and 10% test data.

The results of the accuracy test for the classification of downy mildew with classes DS, DM1, DM2, and DM3, with a comparison of 90% training data and 10% test data, showed that the accuracy performance of the LGBM model was 60%, Random Forest was 72%, and XGBoost was 67%. The best accuracy performance of 72% was obtained by the Random Forest model.

*2) Scenario 2*: The dataset was divided into training and test data at a ratio of 80% training data and 20% test data. The classification results for LGBM, Random Forest, and XGBoost are shown in Fig. 6.
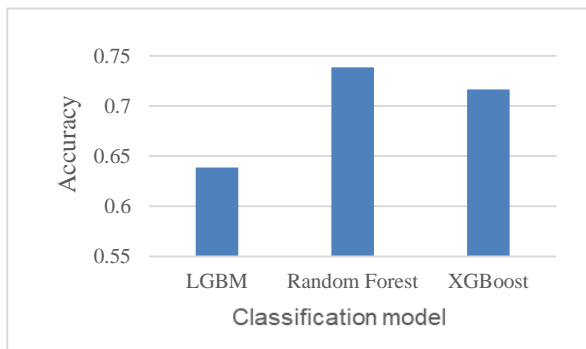


Fig. 6.    Accuracy with 80% training data and 20% test data.

The results of the accuracy test for the classification of downy mildew with classes DS, DM1, DM2, and DM3, with a comparison of 80% training data and 20% test data, showed that the accuracy of the LGBM model was 63%, Random

Forest 73%, and XGBoost 71%. The best accuracy performance of 73% was obtained by the Random Forest model.

*3) Scenario 3*: The dataset was divided into training and test data in a ratio of 70% training data and 30% test data. The classification results for LGBM, Random Forest, and XGBoost are shown in Fig. 7.
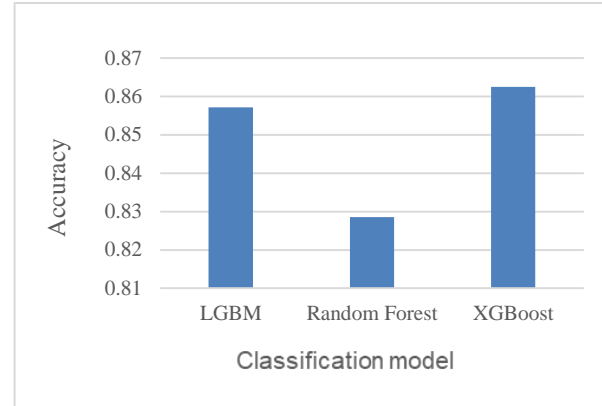


Fig. 7.    Accuracy with 70% training data and 30% test data.

The results of the accuracy test for the classification of downy mildew disease with classes DS, DM1, DM2, and DM3, with a comparison of 70% training data and 30% test data, showed that the performance accuracy of the LGBM model was 85%, Random Forest was 82%, and XGBoost was 86%.

## IV. DISCUSSION

The classification of melon leaf disease is divided into four classes, namely DS, DM1, DM2, and DM3, with feature extraction that uses colour, texture, Shannon entropy, and canny edge features. The results of feature extraction are in the form of combined features, with a total of 838 features. The combined features were then modelled using the LGBM, Random Forest, and XGBoost. Results of evaluating the confusion metrics with a comparison of training and test data scenarios, namely scenarios 1, 2, and 3. The results of testing the first scenario showed that the best accuracy performance model obtained by Random Forest was 72%. The results of testing scenario 2 with the best accuracy performance were obtained by Random Forest, that is, 73%. The results of testing scenario 3 showed that the best accuracy performance of 86% was obtained by the XGBoost model. The best average accuracy for testing the Random Forest, LGBM, and The use of more test data can be seen in scenarios 1, 2, and 3, and the accuracy performance of the Random Forest, LGBM and XGBoost models increased. The combined features of 838 features caused when the model was executed, the running process took a long time, and the accuracy of the model performance was at most 90%. While there were 838 combined features, there were still redundant and irrelevant features. The problem of redundant and irrelevant features requires further investigation.

## V. CONCLUSION

Melon leaf disease, namely downy mildew, spreads very quickly; therefore, if it is not controlled properly, it can cause melon plants to die. Determining the level of downy mildew disease on melon leaves is important; this is done to determine the development of downy mildew disease that infects the leaves. One method to determine the level of downy mildew disease is to use a melon leaf disease classification model. The aim of this study was to create a classification model for downy mildew disease levels in melon leaves, namely DS, downy DM1, DM2, and DM3, using combined features, namely texture, colour, Shannon entropy, and edge features. The results of the extraction of colour, texture, entropy, and canny features resulted in 521 colour features, 60 texture features, 1 entropy feature, and 256 canny edge features; thus, the total number of combined features was 838 features. The model was evaluated using a confusion matrix, and a scenario was created by dividing the training data and test data into scenarios 1, 2, and 3. The results of accuracy testing for the classification of downy mildew disease with classes DS, DM1, DM2, and DM3 in scenario 1 showed that the accuracy performance of the LGBM model was 60%, Random Forest was 72%, and XGBoost was 67%. Accuracy comparison with scenario 2 and testing was carried out, with the accuracy performance results of the LGBM model being 63%, Random Forest 73%, and XGBoost 71%. Accuracy comparison with Secanrio 3 and model testing was carried out with the results of LGBM model accuracy performance testing of 85%, Random Forest 82%, and XGBoost 86%. Based on testing with scenarios 1, 2, and 3, the best average accuracy of testing the Random Forest, LGBM, and tested more data than in scenarios 1 and 2. The use of more test data can be observed in scenarios 1, 2, and 3, and the accuracy performance of the Random Forest, LGBM and XGBoost models increased.

## REFERENCES

[1] L. Sinaga, N. Zahara, P. Tanaman, F. Pertanian, and U. Bengkulu, "Kajian Patogen Penyebab Penyakit Pada Tanaman Melon (Cucumis melo L.) di Bengkulu," Konserv. Hayati, vol. 18, no. 1, pp. 22–25, 2022.

[2] A. Ozbahce et al., "Impact of different rootstocks and limited water on yield and fruit quality of melon grown in a field naturally infested with Fusarium wilt," Sci. Hortic. (Amsterdam)., vol. 289, no. April, p. 110482, 2021.

[3] S. Kaur, S. Pandey, and S. Goel, "Plants Disease Identification and Classification Through Leaf Images: A Survey," Arch. Comput. Methods Eng., vol. 26, no. 2, pp. 507–530, 2019.

[4] J. Basavaiah and A. Arlene Anthony, "Tomato Leaf Disease Classification using Multiple Feature Extraction Techniques," Wirel. Pers. Commun., vol. 115, no. 1, pp. 633–651, 2020.

[5] Andreanov Ridhovan, Aries Suharso, and Chaerur Rozikin, "Disease Detection in Banana Leaf Plants using DenseNet and Inception Method," J. RESTI (Rekayasa Sist. dan Teknol. Informasi), vol. 6, no. 5, pp. 710–718, Oct. 2022.

[6] J. Arora, U. Agrawal, and P. Sharma, "Classification of Maize leaf diseases from healthy leaves using Deep Forest," J. Artif. Intell. Syst., vol. 2, no. 1, pp. 14–26, 2020.

[7] M. A. Khan, T. Akram, M. Sharif, K. Javed, M. Raza, and T. Saba, "An automated system for cucumber leaf diseased spot detection and classification using improved saliency method and deep features selection," Multimed. Tools Appl., vol. 79, no. 25–26, pp. 18627–18656, 2020.

[8] L. C. Ngugi, M. Abelwahab, and M. Abo-Zahhad, "Recent advances in image processing techniques for automated leaf pest and disease recognition – A review," Inf. Process. Agric., vol. 8, no. 1, pp. 27–51, 2021.

[9] K. K. Thyagharajan and I. Kiruba Raji, "A Review of Visual Descriptors and Classification Techniques Used in Leaf Species Identification," Arch. Comput. Methods Eng., vol. 26, no. 4, pp. 933–960, 2019.

[10] G. Dhingra, V. Kumar, and H. D. Joshi, "Study of digital image processing techniques for leaf disease detection and classification," Multimed. Tools Appl., vol. 77, no. 15, pp. 19951–20000, Aug. 2018.

[11] V. K. Vishnoi, K. Kumar, and B. Kumar, Plant disease detection using computational intelligence and image processing, no. 0123456789. Springer Berlin Heidelberg, 2020.

[12] G. Hu, H. Wang, Y. Zhang, and M. Wan, "Detection and severity analysis of tea leaf blight based on deep learning," Comput. Electr. Eng., vol. 90, no. January 2020, p. 107023, 2021.

[13] P. Wspanialy and M. Moussa, "A detection and severity estimation system for generic diseases of tomato greenhouse plants," Comput. Electron. Agric., vol. 178, no. January, p. 105701, 2020.

[14] S. Chen et al., "An approach for rice bacterial leaf streak disease segmentation and disease severity estimation," Agric., vol. 11, no. 5, 2021.

[15] S. Sachar and A. Kumar, "Survey of feature extraction and classification techniques to identify plant through leaves," Expert Syst. Appl., vol. 167, p. 114181, 2021.

[16] N. Salem, H. Malik, and A. Shams, "Medical image enhancement based on histogram algorithms," Procedia Comput. Sci., vol. 163, pp. 300–311, 2019.

[17] E. A. Sekehravani, E. Babulak, and M. Masoodi, "Implementing canny edge detection algorithm for noisy image," Bull. Electr. Eng. Informatics, vol. 9, no. 4, pp. 1404–1410, 2020.

[18] P. Bromiley, "Shannon entropy, Renyi entropy, and information," Stat. Inf. Ser., no. 2004, pp. 1–8, 2004.

[19] J. Xu, Y. Zhang, and D. Miao, "Three-way confusion matrix for classification: A measure driven view," Inf. Sci. (Ny)., vol. 507, pp. 772–794, 2020.

[20] A. Sharma, A. Mittal, S. Singh, and V. Awatramani, "Hand Gesture Recognition using Image Processing and Feature Extraction Techniques," Procedia Comput. Sci., vol. 173, no. 2019, pp. 181–190, 2020.

# A Vision-based Human Posture Detection Approach for Smart Home Applications

Yangxia Shu[1]*, Lei Hu[2]

College of Big Data Science, Jiangxi Institute of Fashion Technology, Nanchang 330201, Jiangxi, China[1]
Information Technology Integration Innovation Center, Intelligent Research and Innovation Team for Clothing,
Jiangxi Institute of Fashion Technology, Nanchang 330201, Jiangxi, China[1, 2]
Operation and Maintenance Section of Asset Department, Jiangxi Institute of Fashion Technology,
Nanchang 330201, Jiangxi, China[2]

*Abstract*—**Effective posture identification in smart home applications is a challenging topic for people to tackle in order to decrease the occurrence of improper postures. Vision-based posture identification has been used to construct a system for identifying people's postures. However, the system complexity, low accuracy rate, and slow identification speed of existing vision-based systems make them unsuitable for smart home applications. The goal of this project is to address these issues by creating a vision-based posture recognition system that can recognize human position and be used in smart home applications. The suggested method involves training and testing a You Only Look Once (YOLO) network to identify the postures. This Yolo-based approach is based on YOLOv5, which provides a high accuracy rate and satisfied speed in posture detection. Experimental results show the effectiveness of the developed system for posture recognition on smart home applications.**

*Keywords*—*Posture identification; smart home applications; vision-based recognition; YOLO network; accuracy*

## I. INTRODUCTION

Recognition of human body position has been extensively utilized in the fields of detection and rescue, intelligent monitoring, and other areas of computer vision as one of the most significant research paths. Its major objective is to study different human body areas, extract posture information, and eventually recognize human body position using computer vision technology [1].

Healthcare concerns are suddenly becoming more and more crucial as the number of senior individuals worldwide rises. Human motion capture technologies are necessary for older adults who live alone in order to address these problems. Seniors' health may also be tracked by observing their posture, and if high-risk postures, such as falling over, are noticed, a warning can be sent. These solutions will ease the strain on human resources while enhancing posture recognition effectiveness [2]. However, due to variables such as shifting viewing angles, human body occlusion, and appearance variations, determining the human posture with accuracy is a highly difficult process [1, 3].

In recent years, there has been remarkable progress in image processing, thanks to the advancements in deep learning, particularly convolutional neural networks (CNN). These networks draw inspiration from the hierarchical processing observed in the human visual cortex. By employing CNN, the process of feature extraction and classification has been revolutionized, as it allows the network to discern crucial features from the provided training data automatically. As a result, CNN has demonstrated remarkable success in accurate image processing [4]. A multi-layer neural network called CNN is mostly employed to scale and recognize displacement in two-dimensional visuals. The convolutional neural network's layers each represent a change. Common methods include convention and pooling transformation. Each transformation expresses different features from the input features as well processes the input data in a specific way. Each layer is made up of several two-dimensional planes containing the feature map that each layer has processed [5]. Each output characteristic is also an input feature; however, the value's computation process is the same. It is compatible with the generic neural network since it is the dot product of the weight and the input before the bias is imposed.

Within the realm of posture detection algorithms based on CNN, two primary types can be identified. The first category consists of two-stage detection algorithms, which involve a two-step process: locating the target and then recognizing it. Among these, the Region-Convolutional Neural Network (R-CNN) is a well-known traditional technique. However, it has shown poor performance and fails to meet real-time processing demands [6]. To address this limitation, subsequent advancements were made, giving rise to the Fast regions with CNN (Fast R-CNN) and faster regions with CNN (Faster R-CNN). Despite these improvements, they still do not fully satisfy real-time expectations [6]. The second category involves a one-stage detection technique, streamlining target localization and identification into a single action. Within this approach, examples like the single shot multi-box detector (SSD) series and the you only look once (YOLO) series are commonly cited as traditional instances of this methodology [7]. These methods have been developed to achieve faster and more efficient posture detection compared to the two-stage approaches.

The YOLO is regarded as one of the most effective and least time-consuming posture identification techniques. The YOLO model is used in several applications, including recognizing pedestrians and cars in traffic situations, monitoring livestock, aerial analysis, and even helping the visually handicapped identify faces. YOLO is an accurate posture detection method that combines a grid methodology

with the CNN architecture [8]. The YOLOv5 algorithm has been proposed as a modification of the YOLO algorithm version. On the basis of greater precision and a smaller model, YOLOv5's detection speed has significantly increased when compared to YOLOv3. The YOLOv5 technique has not yet found widespread application in the field of fall detection. Thus, this paper will enhance the model based on YOLOv5 research and apply it to the detection of senior fall behavior. The four network models of the target detection network based on YOLOv5 are YOLOv5s, YOLOv5m, YOLOv5l, and YOLOv5x. The three models of YOLOv5m, YOLOv5l, and YOLOv5x are the results of continual deepening and broadening based on YOLOv5s, which have the least depth and the smallest feature map width among them [7]. The YOLOv5 network is divided into the following four sections: the neck, the backbone, and the prediction.

The research contributions of this study are listed as follows:

*1)* The research contributes to the field of smart home applications by addressing the challenges of effective posture identification. It proposes a vision-based posture recognition system that overcomes the limitations of existing systems, such as complexity, low accuracy, and slow identification speed, thus making it suitable for integration into smart homes.

*2)* The study introduces a novel approach to posture recognition by leveraging the You Only Look Once (YOLO) network, specifically YOLOv5, which significantly improves accuracy and detection speed. This innovation enhances the viability of posture recognition systems for real-time monitoring and intervention in smart home environments.

*3)* Experimental results confirm the effectiveness of the developed YOLO-based posture recognition system in smart home applications. This research contribution showcases the practical applicability of the proposed method for reducing improper postures and enhancing the overall well-being of smart home residents.

The paper is organized as follows: Section II provides an introduction to the background of the study, offering essential context to the reader. In Section III, a comprehensive explanation of the methodology is presented, covering both the training and testing processes involved in human posture detection using the YOLO 5 network. Section IV delves into a detailed discussion and analysis of the obtained results, shedding light on the outcomes of the experiments and their implications. Finally, in Section V, the paper concludes with a summary of the findings and potential future directions for further research in this domain.

## II. RELATED WORKS

In study [9], a technique for skeleton-based online HAR employing ST-GCN with a sliding window and majority voting approach using convolutional neural networks (STGCN-SWMV) has been developed in order to address the issue of online HAR for continuous flow skeleton data. Two online skeleton-based datasets called OAD and UOW have been used to assess this approach. By automatically learning geographical and temporal information, this method offers greater prediction power and generalizability. The goal of this work is to increase online recognition performance, and it is suggested that in order to do this, textual information about item appearance or human interaction may be integrated to provide more learning characteristics.

A deep convolutional neural network has been proposed as a method for recognizing human action from depth maps and posture data. To maximize feature extraction, three convolutional neural network channels and two action representations are combined. The trials demonstrate that employing three channels instead of one or using two channels alone produces superior outcomes. In order to classify human activities using one or two CNN channels at most for quick computations, the challenge of this work is to reduce the number of CNN channels [4].

To address these problems, the study in [10] demonstrates the Trajectory-weighted Deep Convolutional Rank-Pooling Descriptor (TDRD) for fall detection, which is resilient to surrounding settings and can successfully represent the dynamics of human motions in extended films. The SDUF all dataset had better results with TDRD, and the UR dataset and multi-camera datasets with SVM classifiers saw equivalent performance. The problem with the TDRD algorithm is that although it excels at detecting single falls, it struggles to do so in scenarios involving many people. Additionally, TDRD is a problem with characterizing prolonged static postures.

The author in [11] presented an innovative approach to human fall detection, leveraging the Fast Pose Estimation technique. The proposed method involves classifying data extracted from image frames using two models: Time-Distributed Convolutional Neural Network Long Short-Term Memory (TD-CNN-LSTM) and 1-Dimensional Convolutional Neural Network (1D-CNN). The results demonstrate impressive accuracy, making this technique a valuable addition to the realm of reliable human fall detection. One notable advantage of this approach is its suitability for implementation on edge devices, thanks to its low computational and memory requirements. This is achieved by integrating the previously untapped potential of the Fast Pose Estimation method, which had not been utilized for this specific purpose before. With its efficient utilization of resources and strong performance, the suggested technique holds significant promise in enhancing human fall detection systems.

The paper in [17] presented an approach to human fall detection in smart home environments by utilizing YOLO (You Only Look Once) networks. The research aims to enhance the safety and care provided in smart homes by addressing the critical issue of detecting human falls. The YOLO-based approach, specifically YOLOv5, is proposed as an efficient and accurate method for real-time fall detection. The paper discusses the development and implementation of this system, emphasizing its potential to improve the quality of care and response within smart home setups, thereby contributing to the broader field of healthcare and assisted living technology.

The paper in [18] developed a method for analyzing and deducing errors in human posture to mitigate musculoskeletal disorders among construction workers. The study employs

vision-based techniques to monitor and assess the postures of construction workers, aiming to identify and rectify potentially harmful positions. The findings suggest that this approach effectively reduces the risk of musculoskeletal disorders in the construction industry by providing real-time feedback and guidance on proper posture. However, a limitation of the study is not extensively discussing the practical implementation challenges and feasibility of the proposed vision-based system in real-world construction settings, which may require further investigation and adaptation.

The paper in [19] provided a comprehensive overview of the current state of research in vision-based indoor Human Activity Recognition. The review delves into the latest advancements in this field, highlighting the diverse applications and methodologies employed for recognizing human activities indoors using computer vision techniques. It discusses the challenges encountered, such as occlusions, variability in lighting conditions, and the need for large annotated datasets, which affect the accuracy and robustness of existing systems. The paper also presents future prospects, emphasizing the potential of deep learning models like Convolutional Neural Networks (CNNs) and recurrent networks to improve HAR accuracy, as well as the integration of multimodal sensor data to enhance performance. Overall, this review offers valuable insights into the current landscape of vision-based indoor HAR, pinpointing areas where further research and innovation are required to overcome existing challenges and unlock its full potential in various applications.

## III. METHODOLOGY

YOLO was developed as a pretrained posture detector that can identify common items, including tables, chairs, automobiles, phones, and more. To develop a model capable of detecting human postures, such as those associated with walking, sitting, and falling. A detection technique based on YOLOv5 is what we suggest. Additionally, real-time is needed to detect and track the target [12]; therefore, our model performs well when used in real-time.

### A. Dataset

For dataset preparation, images were collected from various sources, including Internet's webpages, and the Kaggle dataset [13], and created a custom posture dataset. This dataset involves images with three human posture classes: walking, sitting, and falling. The images directory contains two subdirectories (374 images) used for training and Val (111 images) for validation. The Labels directory contains two subdirectories, train and Val, and here in this directory, we have text files with labels for that particular image. Fig. 1 shows some examples of our dataset.

To enhance the performance of our model, we expanded the dataset from 374 images to 1092 images through augmentation using Roboflow. For each original image, up to five augmented versions were generated. These augmentations were applied randomly, involving rotations with hue variations ranging from -50° to +50°, adjustments in brightness within -40% to +40%, exposure changes between -35% to +35%, blurring up to 1 pixel, and the introduction of noise up to 5%-pixel value. Regarding the validation dataset, it consists of three distinct sets. The primary dataset remains unchanged, while the other two sets were obtained by applying different preprocessing techniques and augmentations.

In one of the preprocessing suites, the images were resized to 416x640, followed by automatic contrast adjustment using adaptive equalization, grayscale conversion, and incremental adjustments in brightness (between -40% and +40%) and exposure (between -21% and +21%). In another preprocessing set, the images were resized to 640x480, followed by automatic contrast adjustment using adaptive equalization. Additionally, brightness adjustments (between -40% and +40%), exposure alterations (between -21% and +21%), and 90° rotations (both clockwise and counterclockwise) were applied. For illustrative purposes, Fig. 2 showcases some examples of the augmented images resulting from these transformations.



Fig. 1.    Sample images from the dataset.

Fig. 2.    Sample images of augmented images.

### B. Google Colab

To conduct our experiments, we took advantage of the resourceful GPUs available through Google Colab, which offers free access to this powerful computing technology. Specifically, we utilized a 12GB NVIDIA Tesla T4 GPU for all our training and testing tasks. During the training phase, our model underwent 20 epochs, with a batch size 16, and the images were resized to a dimension of 640. Additionally, we maintained YOLOv5s's default settings for other hyperparameters to ensure consistency and fair comparison. For optimization purposes, we employed the Stochastic Gradient Descent (SGD) optimizer, setting the learning rate (lr) to 0.001, which further contributed to the effectiveness of our model during training.

### C. Training and Testing

When embarking on the training of a posture detector, a highly effective strategy involves commencing with a pre-existing model that has been trained on extensive datasets. In this approach, the weights of this existing model are utilized as a starting point for training, even if the model's pre-trained weights do not directly encompass the specific postures required for the current experiment. This technique is commonly referred to as transfer learning. To expedite the learning process and enable faster convergence, we opted to utilize a pretrained model that incorporates weights previously trained on the COCO dataset. By leveraging this pretrained model as a starting point, our network can grasp and adapt to the novel posture detection task more swiftly and efficiently.

In this study, our total dataset consists of 1425 images, 70% of which are used for training, 20% for validation, and 10% for testing. 70% of training includes 1092 images, 20% of validation includes 333 images, and the rest of the images are considered for testing.

## IV.    RESULTS AND ANALYSIS

In this section, we introduce the experiment's details, and then we show the training results using pretraining weights and compare the three models of YOLOv5. Then we validated the model on 333 photos. The experimental results adopt the average precision mean mAP and the number of frames per second (FPS). Correspondingly, for each category of postures, we calculated the Precision rate and Recall rate [2]. The results are shown in Fig. 3.

### A. Performance Analysis

This section presents the performance analysis of Yolo models. The analysis justifies the usage of the Yolo algorithm and the specified version as YOLOv5. To perform this analysis, a comparison of Yolo models is presented.

When comparing different versions of YOLO models, accuracy and speed are two key metrics to consider. Accuracy refers to how well the model can detect and classify posture correctly. A more accurate model will have higher precision and recall in identifying postures in an image. Speed, on the other hand, relates to the inference time required for the model to process an image and provide the output. Faster models are desirable for real-time applications where quick posture detection is essential. Fig. 4 shows the comparing different versions of YOLO models on accuracy and speed [14].

As shown in Fig. 5, it's important to strike a balance between accuracy and speed, as a highly accurate model might sacrifice speed, while a faster model might compromise accuracy. Thus, when evaluating YOLO models, it is crucial to assess their performance based on accuracy and speed to choose the most suitable option for the intended use case. When comparing YOLO models based on accuracy and speed metrics, YOLOv5 stands out as a superior choice. YOLOv5 showcases significant improvements in both accuracy and speed compared to its predecessors, YOLOv3 and YOLOv4. Through optimized architecture and advanced training

strategies, YOLOv5 achieves better accuracy by accurately detecting and classifying postures in various scenes.

Additionally, YOLOv5 introduces model scaling options, allowing customization for specific requirements and striking a balance between accuracy and speed based on the task. Furthermore, its efficient inference techniques and streamlined design lead to faster processing times, making YOLOv5 ideal for real-time applications where quick posture detection is crucial. The overall enhancement in both accuracy and speed positions YOLOv5 as a top-performing posture detection model, making it a preferred choice for a wide range of computer vision applications.

Moreover, another graph is presented to represent the comparison of various YOLO models in terms of average precision (AP) while conducting the evaluation on YOLOv5l

across different releases, YOLOv4 with different releases, and YOLOv3. The x-axis represents GPU time with a batch size of 8, indicating the time taken by the GPU to process the images. The y-axis represents the average precision (AP), which measures the accuracy of posture detection. Fig. 6 demonstrates the comparison of various YOLO models in terms of AP [15, 16].

As shown in Fig. 5, in analyzing the graph, it becomes evident that YOLOv5 consistently demonstrates better AP compared to YOLOv4 and YOLOv3. This indicates that YOLOv5 achieves more accurate posture detection across the evaluated releases. The higher AP scores attained by YOLOv5l across different releases suggest that its advancements in architecture, training strategies, and inference optimizations have significantly improved detection accuracy.
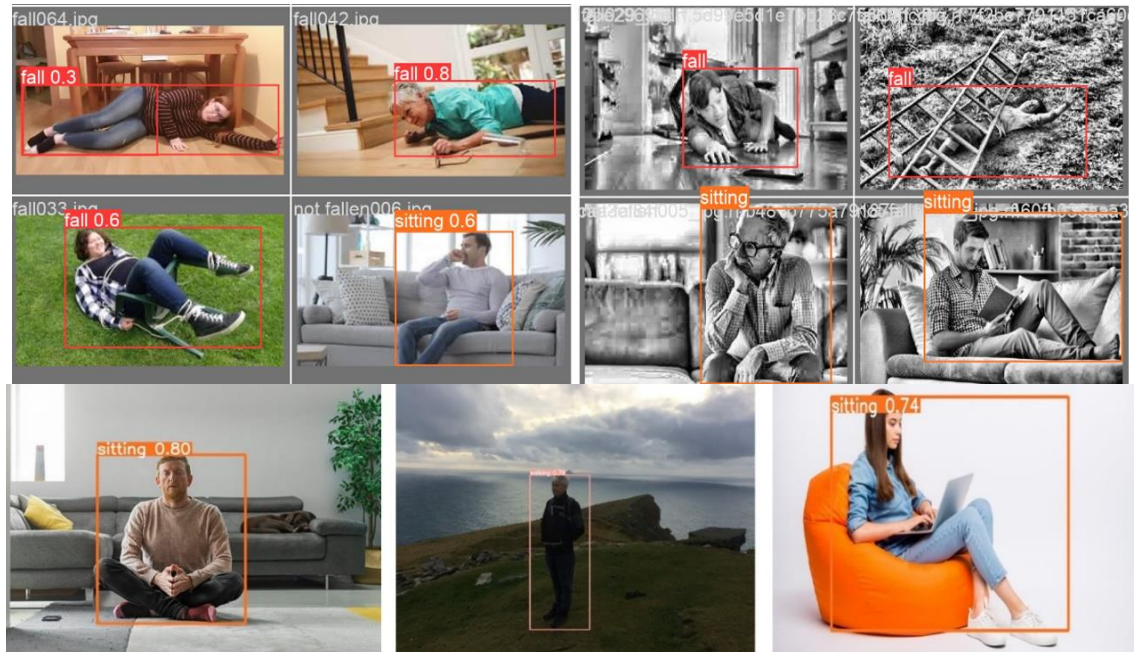


Fig. 3. Samples of experimental results.
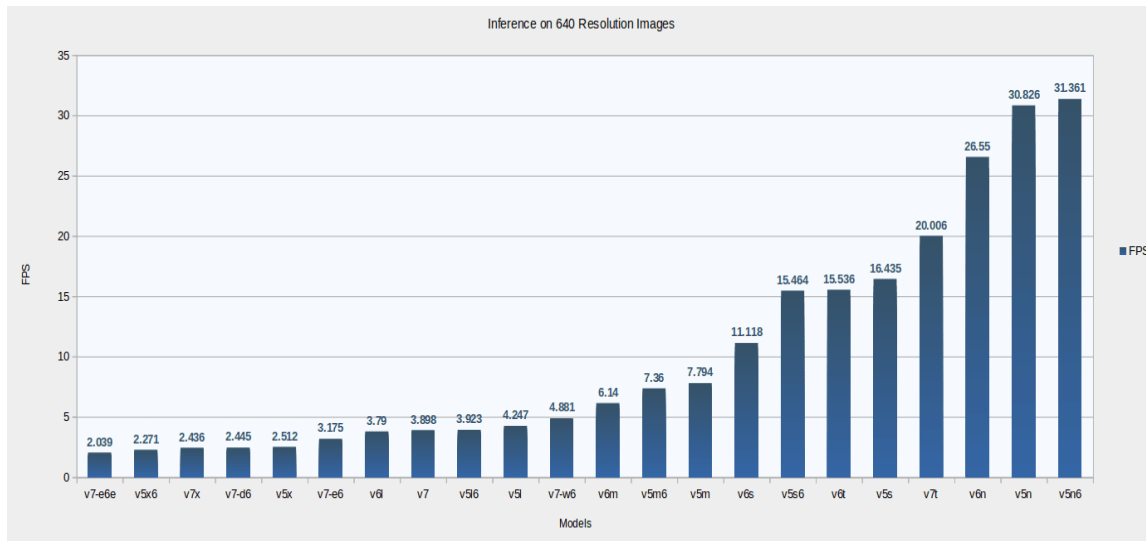


Fig. 4. Comparison of Yolo models based on accuracy and speed.
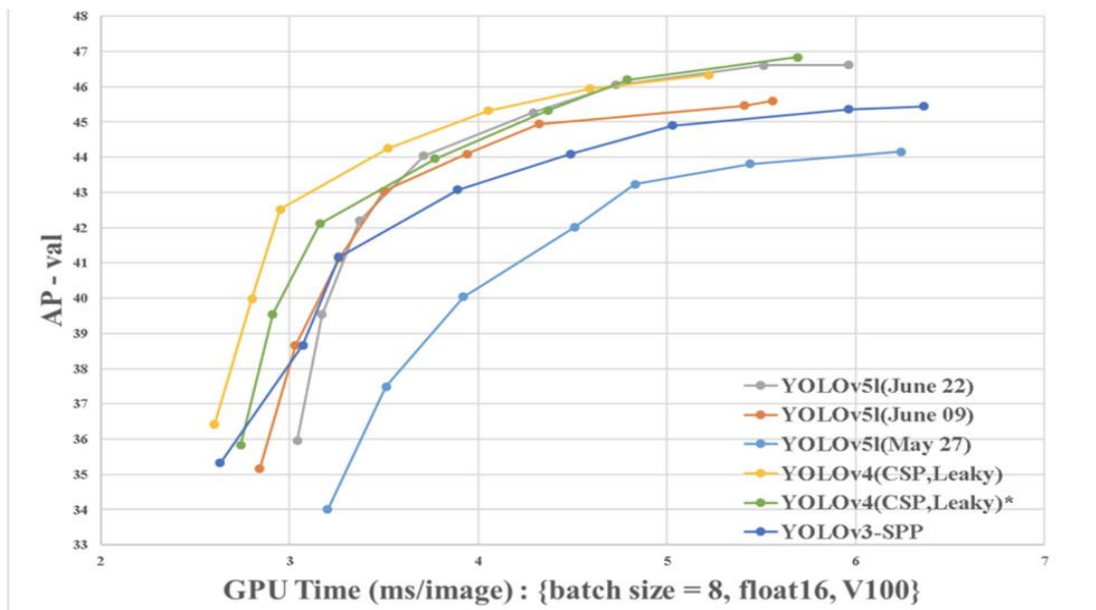
Fig. 5.    Comparison of Yolo algorithm on average precision (AP).

Furthermore, the graph allows us to observe the trade-off between GPU time and AP for each model. By analyzing the trend lines or data points, it becomes apparent that YOLOv5 strikes a favorable balance between accuracy and GPU processing time. It manages to achieve higher AP scores while maintaining comparable or even faster GPU processing times compared to the other models.

Finally, the performance of the proposed method is evaluated based on precision, recall, and mAP. When evaluating the performance of a generated model for human posture detection, precision, recall, and mean Average Precision (mAP) are key metrics to consider. Precision measures the accuracy of positive predictions, indicating how well the model identifies true positives and minimizes false positives. Recall quantifies the model's ability to detect all relevant human postures, minimizing false negatives. These metrics help assess the model's accuracy and completeness in detecting human postures. Additionally, mAP combines precision and recall across various confidence thresholds, providing an overall measure of the model's performance. It allows for a comprehensive evaluation of the model's accuracy at different recall levels, offering insights into its performance across the entire range of detection thresholds.

By analyzing precision, recall, and mAP, one can gain a comprehensive understanding of the model's ability to accurately detect human postures while striking a balance between false positives and false negatives. Based on our experimental results, the first version of our model was trained with 1092 photos. This model achieved relatively good results. Table I shows the model evaluation in our proposed approach.

As shown in Table I, the table provides detailed performance metrics for a human posture detection model across different classes: "all," "fall," "walking," and "sitting." Let's examine each column as Class: This column represents the specific class or category of human postures for which the performance metrics are provided. Images: It indicates the

number of images in the dataset that contain instances of the corresponding class. Instances: This column shows the total number of instances or occurrences of the specific class within the dataset. Precision: Precision measures the accuracy of the model's positive predictions for each class. It indicates the proportion of correctly identified instances out of all the predicted instances for that class. Higher precision values indicate a lower rate of false positives. Recall: Recall, also known as sensitivity, represents the model's ability to detect all relevant instances of the class. It calculates the proportion of correctly identified instances out of all the actual instances for that class. Higher recall values indicate a lower rate of false negatives. mAP50: (mAP at IoU threshold 0.50) evaluates the overall detection accuracy of the model. It measures the average precision across all classes at a specific Intersection over the Union (IoU) threshold of 0.50. Higher mAP50 values indicate better overall detection performance. mAP50-90: mAP50-90 represents the mean Average Precision averaged across all classes, but with IoU thresholds ranging from 0.50 to 0.90. This metric provides a broader assessment of the model's performance by considering a range of IoU thresholds.

As depicted in Fig. 6, analyzing the table, we can observe the overall performance of the model, represented by the "all" class, achieves a precision of 0.814, recall of 0.794, mAP50 of 0.825, and mAP50-90 of 0.529. Among the specific classes, the "fall" class achieves the highest precision of 0.909, recall of 0.834, mAP50 of 0.924, and mAP50-90 of 0.539. This indicates that the model performs particularly well in detecting instances of falling postures. The "walking" class shows a high recall of 0.899, indicating that the model effectively detects walking postures while achieving a precision of 0.827 and mAP50 of 0.886. The "sitting" class exhibits lower precision (0.705) and recall (0.649), suggesting that the model faces challenges in accurately detecting instances of sitting postures. It achieves a mAP50 of 0.664, indicating moderate overall performance.

TABLE I.        MODEL EVALUATION METRICS

| Class | Images | Instances | Precision | Recall | mAp50 | Map50-90 |
|---|---|---|---|---|---|---|
| all | 333 | 342 | 0.814 | 0.794 | 0.825 | 0.529 |
| fall | 333 | 216 | 0.909 | 0.834 | 0.924 | 0.539 |
| walking | 333 | 69 | 0.827 | 0.899 | 0.886 | 0.619 |
| sitting | 333 | 57 | 0.705 | 0.649 | 0.664 | 0.429 |
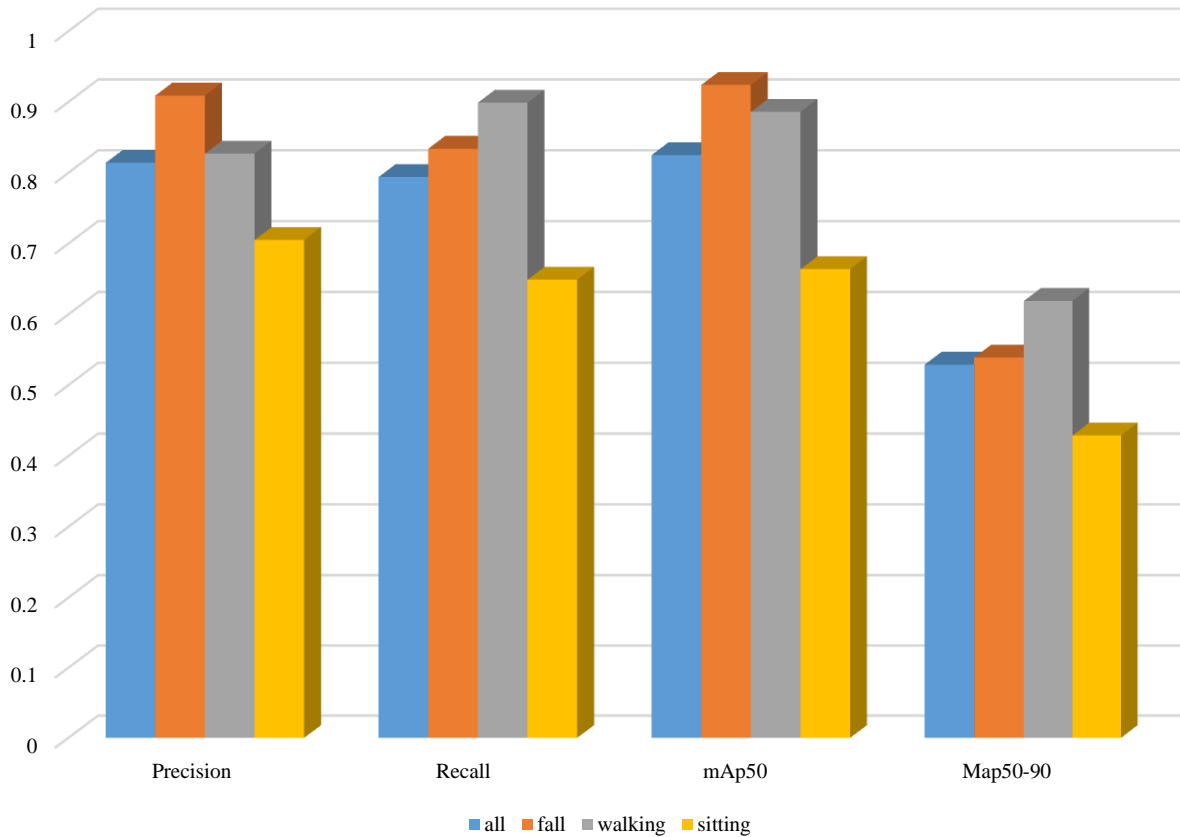


Fig. 6.    Performance analysis of our generated model.

## V.    CONCLUSION

Human posture detection is a challenging task in smart home applications. This study deals with the high complexity, low accuracy, and speed challenges of human posture detection in smart home applications. It intends to develop a vision-based posture recognition system to utilize in smart home applications that can identify human posture. In the proposed approach, a YOLO network is trained and tested to recognize the postures in our custom dataset. This Yolo-based approach is based on YOLOv5, which provides a high accuracy rate and satisfied speed in posture detection. Experimental results show the effectiveness of the developed system for posture recognition on smart home applications. Future research directions could involve refining real-time detection capabilities and exploring user-centric applications, expanding the utility of posture recognition beyond health and safety monitoring to enhance user comfort and experience in smart home environments.

## REFERENCES

[1]  N. Yu, J. Lv, Human body posture recognition algorithm for still images, The Journal of Engineering, 2020 (2020) 322-325.

[2]  W. Quan, J. Woo, Y. Toda, N. Kubota, Human posture recognition for estimation of human body condition, Journal of Advanced Computational Intelligence and Intelligent Informatics, 23 (2019) 519-527.

[3]  A. Aghamohammadi, M.C. Ang, E. A. Sundararajan, N.K. Weng, M. Mogharrebi, S.Y. Banihashem, A parallel spatiotemporal saliency and discriminative online learning method for visual target tracking in aerial videos, Plos one, 13 (2018) e0192246.

[4]  A. Kamel, B. Sheng, P. Yang, P. Li, R. Shen, D.D. Feng, Deep convolutional neural networks for human action recognition using depth maps and postures, IEEE Transactions on Systems, Man, and Cybernetics: Systems, 49 (2018) 1806-1819.

[5]   G. Liu, L. Lin, W. Zhou, R. Zhang, H. Yin, J. Chen, H. Guo, A Posture Recognition Method Applied to Smart Product Service, Procedia CIRP, 83 (2019) 425-428.

[6]   M.C. ANG, A. AGHAMOHAMMADI, K.W. NG, E. SUNDARARAJAN, M. MOGHARREBI, T.L. LIM, MULTI-CORE FRAMEWORKS INVESTIGATION ON A REAL-TIME OBJECT TRACKING APPLICATION, Journal of Theoretical & Applied Information Technology, 70 (2014).

[7]   T. Chen, Z. Ding, B. Li, Elderly Fall Detection Based on Improved YOLOv5s Network, IEEE Access, 10 (2022) 91273-91282.

[8]   S. Sivamani, S.H. Choi, D.H. Lee, J. Park, S. Chon, Automatic posture detection of pigs on real-time using Yolo framework, Int. J. Res. Trends Innov, 5 (2020) 81-88.

[9]   M. Dallel, V. Havard, Y. Dupuis, D. Baudry, A Sliding Window Based Approach With Majority Voting for Online Human Action Recognition using Spatial Temporal Graph Convolutional Neural Networks, 2022 7th International Conference on Machine Learning Technologies (ICMLT), 2022, pp. 155-163.

[10]  Z. Zhang, X. Ma, H. Wu, Y. Li, Fall detection in videos with trajectory-weighted deep-convolutional rank-pooling descriptor, IEEE Access, 7 (2018) 4135-4144.

[11]  M. Salimi, J.J. Machado, J.M.R. Tavares, Using deep neural networks for human fall detection based on pose estimation, Sensors, 22 (2022) 4544.

[12]  M. Ang, E. Sundararajan, K. Ng, A. Aghamohammadi, T. Lim, Investigation of Threading Building Blocks Framework on Real Time Visual Object Tracking Algorithm, Applied Mechanics and Materials, 666 (2014) 240-244.

[13]  U.K. KANDAGATLA, Fall Detection Dataset, 2021.

[14]  Sovit Rath, V. Gupta, Performance Comparison of YOLO Object Detection Models – An Intensive Study, 2022.

[15]  J. Solawetz, What is YOLOv5? A Guide for Beginners., 2020.

[16]  G. Jocher, Ultralytics - yolov5, 2023.

[17]  Bo LU. Human Fall Detection for Smart Home Caring using Yolo Networks. International Journal of Advanced Computer Science and Applications. 2023;14(4).

[18]  Purushothaman MB, Gedara KM. Smart vision-based analysis and error deduction of human pose to reduce musculoskeletal disorders in construction. Smart and Sustainable Built Environment. 2023.

[19]  Bhola G, Vishwakarma DK. A review of vision-based indoor HAR: state-of-the-art, challenges, and future prospects. Multimedia Tools and Applications. 2023 May 11:1-41.

# Object Detectors in Autonomous Vehicles: Analysis of Deep Learning Techniques

Lei Du[*]

Henan Polytechnic Institute Nanyang Henan 473000, China

*Abstract*—**Autonomous vehicles have emerged as a transformative technology with wide-ranging implications for smart cities, revolutionizing transportation systems and optimizing urban mobility. Object detection plays a crucial role in autonomous vehicles, accurately identifying and localizing pedestrians, vehicles, and traffic signs for safe navigation. Deep learning-based approaches have revolutionized object detection, leveraging deep neural networks to extract intricate features from visual data, enabling superior performance in various domains. Two-stage algorithms like R-FCN and Mask R-CNN focus on precise object localization and instance-level segmentation, while one-stage algorithms like SSD, RetinaNet, and YOLO offer real-time performance through single-pass processing. To advance object detection for autonomous vehicles, comprehensive studies are needed, particularly on two-stage and one-stage algorithms. This study aims to conduct an in-depth analysis, evaluating the strengths, limitations, and performance of R-FCN, Mask R-CNN, SSD, RetinaNet, and YOLO algorithms in the context of autonomous vehicles and smart cities. The research contributions include a thorough analysis of two-stage algorithms, a comprehensive examination of one-stage algorithms, and a comparison of different YOLO variants to highlight their advantages and drawbacks in object detection tasks.**

*Keywords—Autonomous vehicles; object detection; deep learning; two-stage object detectors; one-stage object detectors; comprehensive analysis*

## I. INTRODUCTION

Autonomous vehicles have emerged as a groundbreaking technology with wide-ranging implications for smart cities [1, 2]. These vehicles, equipped with advanced sensors and intelligent systems, have the potential to revolutionize transportation systems, enhance road safety, and optimize urban mobility [3]. As autonomous vehicles continue to evolve, their applications in smart cities are becoming increasingly significant, paving the way for efficient and sustainable transportation networks.

Object detection plays a crucial role in the operation of autonomous vehicles [4, 5]. It involves the accurate identification and localization of various objects, such as pedestrians, vehicles, and traffic signs, from sensor data [5]. Reliable object detection is essential for autonomous vehicles to perceive their surroundings, make informed decisions, and navigate complex environments safely [6, 7]. By detecting and tracking objects in real-time, autonomous vehicles can anticipate potential hazards, react accordingly, and ensure the safety of both passengers and pedestrians.

Deep learning-based approaches have emerged as a dominant paradigm in object detection [8, 9]. Leveraging the capabilities of deep neural networks, these approaches have revolutionized the field by automatically learning and extracting intricate features from visual data [10, 11]. They have demonstrated superior performance in a variety of domains, including autonomous vehicles [12], surveillance systems, and robotics [9]. Deep learning-based object detection methods have paved the way for significant advancements in accuracy and real-time processing, enabling more robust and efficient autonomous driving systems.

Two-stage and one-stage object detection algorithms are two popular categories in the field of deep learning-based object detection [13]. In the two-stage category, algorithms such as R-FCN and Mask R-CNN have gained prominence [14]. R-FCN focuses on precise object localization using position-sensitive score maps, while Mask R-CNN introduces instance-level segmentation alongside object detection. In the one-stage category, widely recognized algorithms include SSD, RetinaNet, and YOLO. These models operate with a single pass over the input data, offering real-time performance [15]. SSD utilizes a multi-scale approach with default anchor boxes, RetinaNet addresses class imbalance with the Focal Loss, and YOLO achieves efficient object detection by simultaneously predicting object locations and class probabilities.

To further advance object detection algorithms in autonomous vehicles, there is a need for comprehensive studies that focus on both two-stage and one-stage approaches. Additionally, a comparison of YOLO algorithms, given their popularity, would provide valuable insights into their strengths and weaknesses.

The existing literature on object detection in the context of autonomous vehicles and smart cities tends to prioritize algorithmic performance without delving deeply into real-world implementation, which is a significant gap. To address this, the proposed study should give prominence to how these algorithms function in the dynamic and complex environments of urban areas, considering variables such as weather changes, diverse road users, and intricate traffic scenarios. Additionally, the research should establish a comprehensive and tailored set of evaluation metrics, as the conventional ones might not fully capture the distinct challenges presented by autonomous vehicles in smart cities. Novel metrics, especially those accounting for safety and real-time performance, may be required to provide a more accurate assessment of algorithm effectiveness in this context.

In this study, our aim is to conduct an in-depth analysis of deep learning methods for object detection, with a particular focus on two-stage and one-stage algorithms. This analysis will involve reviewing previous studies, identifying their research contributions, and examining these algorithms' performance, efficiency, and suitability in the context of autonomous vehicles and smart city applications.

The research contributions of this study are as follows:

- Providing a thorough analysis of two-stage object detection algorithms, including R-FCN and Mask R-CNN, and evaluating their strengths and limitations in the domain of autonomous vehicles and smart cities.

- Conducting a comprehensive examination of one-stage object detection algorithms, namely SSD, RetinaNet, and YOLO, and assessing their performance, efficiency, and suitability for real-time applications.

- Comparing and contrasting different YOLO algorithms to highlight their respective advantages, drawbacks, and performance in object detection tasks.

## II. RELATED WORKS

In study [16], a performance analysis of object detection algorithms is presented for traffic surveillance applications, specifically focusing on the use of neural networks. The study evaluates the effectiveness and efficiency of various neural network-based algorithms in detecting and tracking objects in traffic scenes. By analyzing the performance metrics of these algorithms, the paper provides insights into their strengths, limitations, and applicability in traffic surveillance. The aim is to enhance the understanding of object detection and tracking techniques using neural networks, enabling the development of more effective and efficient solutions for traffic surveillance applications.

In study [17], the implementation of a real-time system for detecting traffic signs and road objects was investigated using mobile GPU platforms. The study focuses on developing an efficient and robust algorithm that can accurately identify and classify traffic signs and other objects in real-time. By utilizing mobile GPU platforms, the system achieves high-performance processing and responsiveness. The paper discusses the implementation details, performance evaluation, and practical implications of the proposed approach. The aim of the study is to provide a practical solution for real-time traffic signs and road object detection on mobile devices, contributing to the advancement of intelligent transportation systems.

The study in [18] presented a comparative study of deep learning-based algorithms for road object detection. The study focuses on two-stage and one-stage object detection methods, analyzing their strengths, limitations, and performance in various applications. The algorithms examined include R-FCN, Mask R-CNN, SSD, RetinaNet, and YOLO. The paper reviews previous studies, identifies research contributions, and highlights the need for further analysis and exploration in this field. The objective is to contribute to the advancement of object detection techniques, particularly in the context of road and traffic scenarios.

Finally, in [19], small-object detection in autonomous driving systems is explored using the YOLOv5 algorithm. The study addresses the challenge of accurately detecting small objects, such as pedestrians or traffic signs, which are crucial for safe autonomous driving. By utilizing YOLOv5, the paper proposes an approach that improves the detection performance for small objects in real-time. The study evaluates the effectiveness of the YOLOv5 algorithm and its suitability for autonomous driving applications. The aim is to enhance the object detection capabilities in autonomous driving systems, particularly for small objects, contributing to safer and more reliable autonomous vehicles.

## III. METHODOLOGY

This study conducts a comprehensive analysis of deep learning methods for applications in road object detection, with a specific emphasis on both two-stage and one-stage approaches. Our objective is to address the most superior algorithms in the field. Additionally, it conducts a thorough comparison of the YOLO algorithms, which are widely recognized as the most popular object detection algorithms. By focusing on two-stage and one-stage methodologies and conducting this comparative analysis, it aims to provide valuable insights into the strengths, weaknesses, and performance of these algorithms. The study will contribute to a better understanding of deep learning methods in object detection and help identify the most effective approaches for various applications.

### A. Two-Stages Object Detectors

Two-stage object detectors are a type of deep learning architecture used for object detection tasks. They typically consist of two main stages: region proposal generation and object classification/refinement. These detectors have been widely adopted due to their ability to accurately localize and classify objects in images with complex backgrounds. Inspired from [18], two popular two-stage object detectors are R-FCN [20] and Mask R-CNN [21].

The R-FCN is an object detection model that operates in a fully convolutional manner. In R-FCN, the first stage involves generating a set of region proposals using an external algorithm such as Selective Search. These region proposals serve as potential object locations. In the second stage, R-FCN performs region-based classification and refinement. Instead of using fully connected layers, R-FCN utilizes position-sensitive score maps, which are computed using convolutions. These score maps encode the class probabilities at different spatial locations within each region proposal. Finally, a position-sensitive pooling operation is applied to obtain a fixed-length feature vector for each class. R-FCN achieves state-of-the-art object detection accuracy while being more computationally efficient compared to other two-stage detectors. Fig. 1 shows R-FCN architecture.
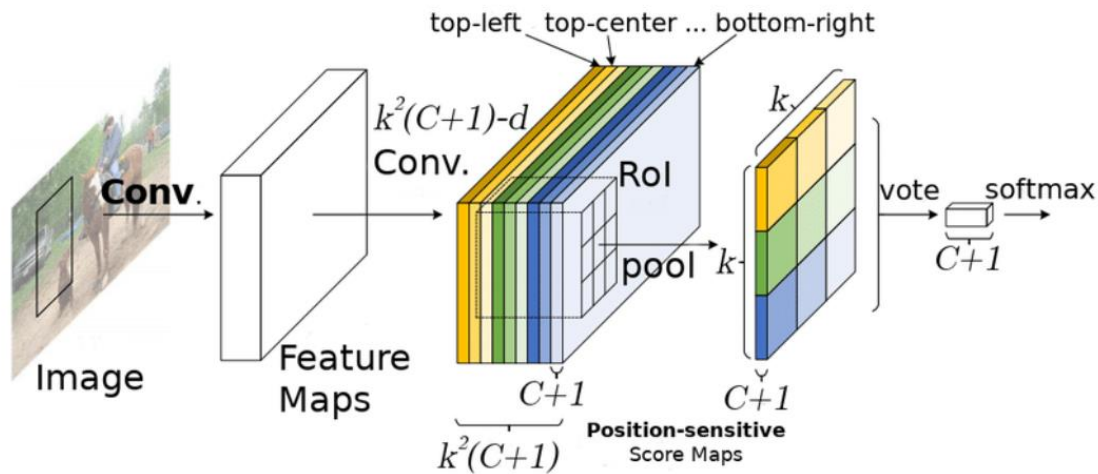
Fig. 1.   R-FCN architecture [22].

The Mask R-CNN is an extension of the Faster R-CNN object detection framework. Similar to Faster R-CNN, Mask R-CNN has two main stages. The first stage involves generating region proposals using a region proposal network (RPN). These proposals are refined and classified in the second stage, similar to Faster R-CNN. However, Mask R-CNN introduces an additional branch that performs instance mask prediction for each region of interest (RoI). This branch produces a binary mask indicating the object's precise boundary. This allows Mask R-CNN to simultaneously handle object detection and segmentation tasks, making it a powerful framework for a wide range of applications, including instance segmentation and object tracking. Fig. 2 shows Mask-RCNN architecture.

*B. One-Stage Object Detectors*

One-stage object detectors are a type of deep learning architecture used for object detection tasks. Unlike two-stage detectors, they directly predict object bounding boxes and class probabilities in a single pass without the need for explicit region proposal generation. This makes one-stage detectors faster and more efficient, making them suitable for real-time applications. Similar to two-stage and inspiring from [18], this study selected three popular examples of one-stage object detectors Single Shot MultiBox Detector (SSD) [24], RetinaNet [25], and You Only Look Once (YOLO) [26].

SSD, also known as the Single Shot MultiBox Detector, is an efficient one-stage object detection model that strikes a balance between high accuracy and real-time processing. The approach employed by SSD involves dividing the input image into a grid of different sizes. Each grid cell takes on the responsibility of predicting bounding boxes and class probabilities for objects within its designated region. This multi-scale strategy enables SSD to effectively detect objects of varying sizes. Additionally, SSD incorporates default anchor boxes with diverse aspect ratios and scales, enhancing the precision of object localization. Through a sequence of convolutional layers that progressively reduce spatial dimensions, SSD efficiently predicts object bounding boxes and class probabilities across multiple scales in a single pass. The architecture of SSD can be visualized in Fig. 3.
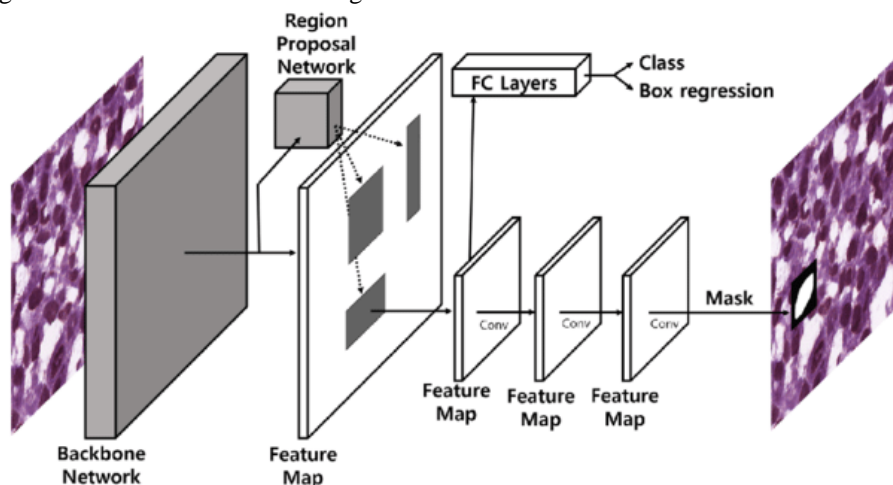


Fig. 2.   Mask-RCNN architecture [23].
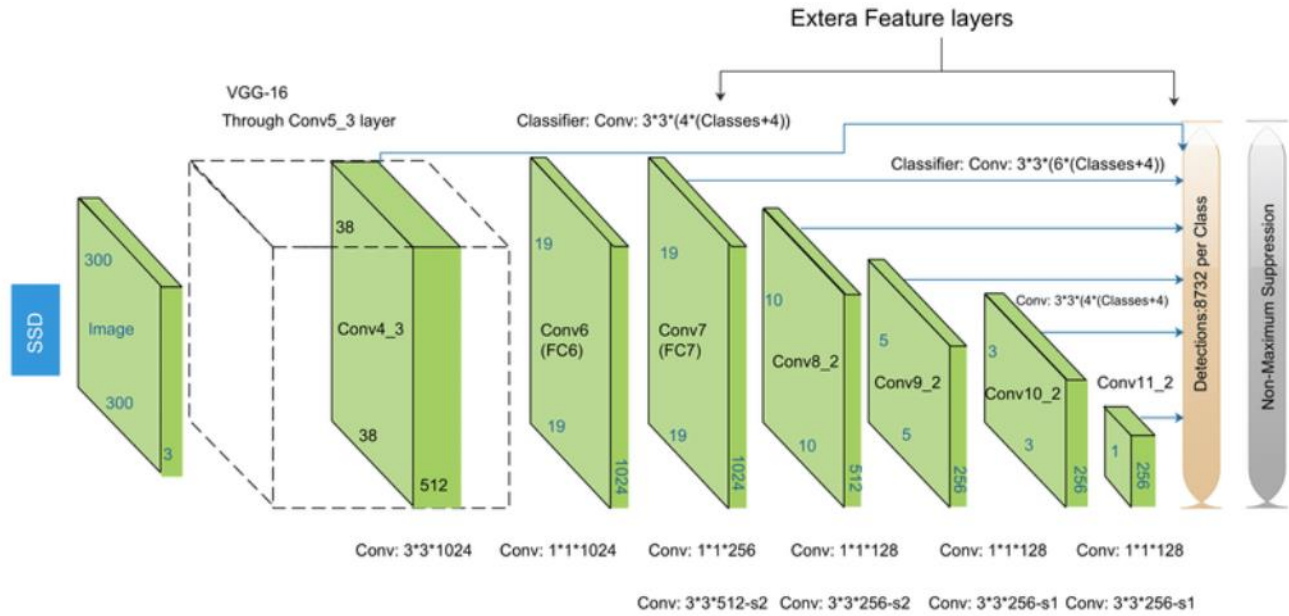
Fig. 3. SSD architecture [27].
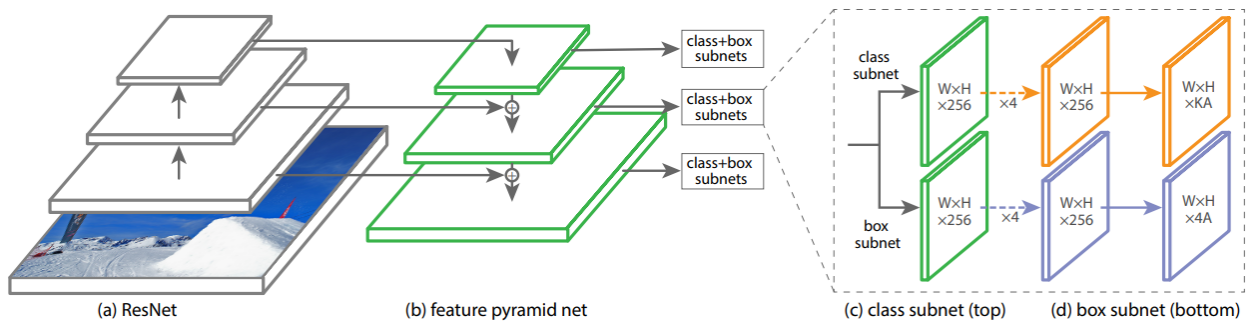


Fig. 4. RetinaNet architecture [25].

RetinaNet is another well-known one-stage object detection system that addresses the issue of imbalanced classes in training. It introduces a unique loss function called Focal Loss, which concentrates on challenging examples that are misclassified or hard to classify. The Focal Loss assigns lower weights to easy examples that are already well-classified, enabling the model to focus more on the difficult examples during the training process. By utilizing this loss function, RetinaNet achieves a better trade-off between accuracy and efficiency. Like SSD, RetinaNet incorporates a feature pyramid network (FPN) that captures multi-scale features and facilitates object detection. The FPN integrates features from different levels of the feature pyramid to effectively handle objects of diverse sizes. The architecture of RetinaNet is depicted in Fig. 4.

YOLO, a groundbreaking one-stage object detection framework, is renowned for its ability to perform in real-time [28]. In contrast to SSD and RetinaNet, YOLO employs a singular neural network that enables simultaneous prediction of object locations and class probabilities, resulting in quicker inference times. Additionally, YOLO incorporates anchor boxes of varying scales and aspect ratios to handle diverse object characteristics. However, earlier versions of YOLO encountered challenges in accurately detecting small objects. The subsequent releases of YOLOv4 and YOLOv5 have introduced enhancements to overcome this limitation, delivering improved speed and competitive performance.

For the parameter setting of the algorithms, following configuration are used, for the YOLOv4, network architecture, image size, learning rate and batch size are set to Darknet-53, 416x416, 0.001, 64. For the Mask R-CNN, backbone architecture, image size, learning rate, mask resolution are set to ResNet-50, 800x800, 0.001, 28x28. For the RetinaNet, backbone architecture, image size, learning rate and batch size are set to ResNet-50, 800x800, 0.0001 and 4. For the R-FCN, backbone architecture, image size, learning rate and batch size are set to ResNet-50, 800x800, 0.001a nd 1. For the SSD, backbone architecture, image size, learning rate and batch size are set to ResNet, 512x512, 0.001 and 32.

## IV. RESULTS AND DISCUSSION

This section discusses the performance analysis of two and one-stage object detectors and the performance analysis of Yolo-based object detectors.

*A. Performance Analysis of Two and Stages Object Detectors*

The PR-curve provides valuable insights into the performance of object detection algorithms [18]. By analyzing this curve, it is possible to assess the precision and recall trade-offs and make informed comparisons between different models.

In Fig. 5, it is evident that YOLOv4 consistently outperforms other models in terms of performance. It achieves the highest precision and recall rates across all levels, demonstrating its effectiveness in accurately detecting objects in various scenarios. The two-stage detection model of Mask R-CNN exhibits commendable precision and recall, surpassing RetinaNet, R-FCN, and SSD, indicating its superior overall detection accuracy and efficiency.

When comparing R-FCN with SSD, it is observed that R-FCN outperforms SSD in terms of precision for target detection at all levels. This indicates that R-FCN provides more precise detection results, enhancing the reliability of the object detection process. Furthermore, the recall of Mask R-CNN closely matches that of YOLOv4, specifically for target detection with occlusion and truncation, suggesting that Mask R-CNN can accurately detect objects even in challenging scenarios where occlusion and truncation are present.

However, it should be noted that SSD exhibits the lowest recall among all the models, indicating a higher rate of missed detections for targets at all levels. This suggests that SSD may struggle to detect objects accurately compared to the other models. Therefore, based on the PR-curve analysis, YOLOv4 emerges as the best-performing model overall, followed by Mask R-CNN. R-FCN surpasses SSD in terms of precision, while SSD exhibits the lowest recall rate. These insights provide valuable guidance for selecting the most suitable object detection algorithm based on specific requirements and priorities.



(a) Vehicle

(b)Pedestrian

(a) Traffic Sign

(b) Traffic Light
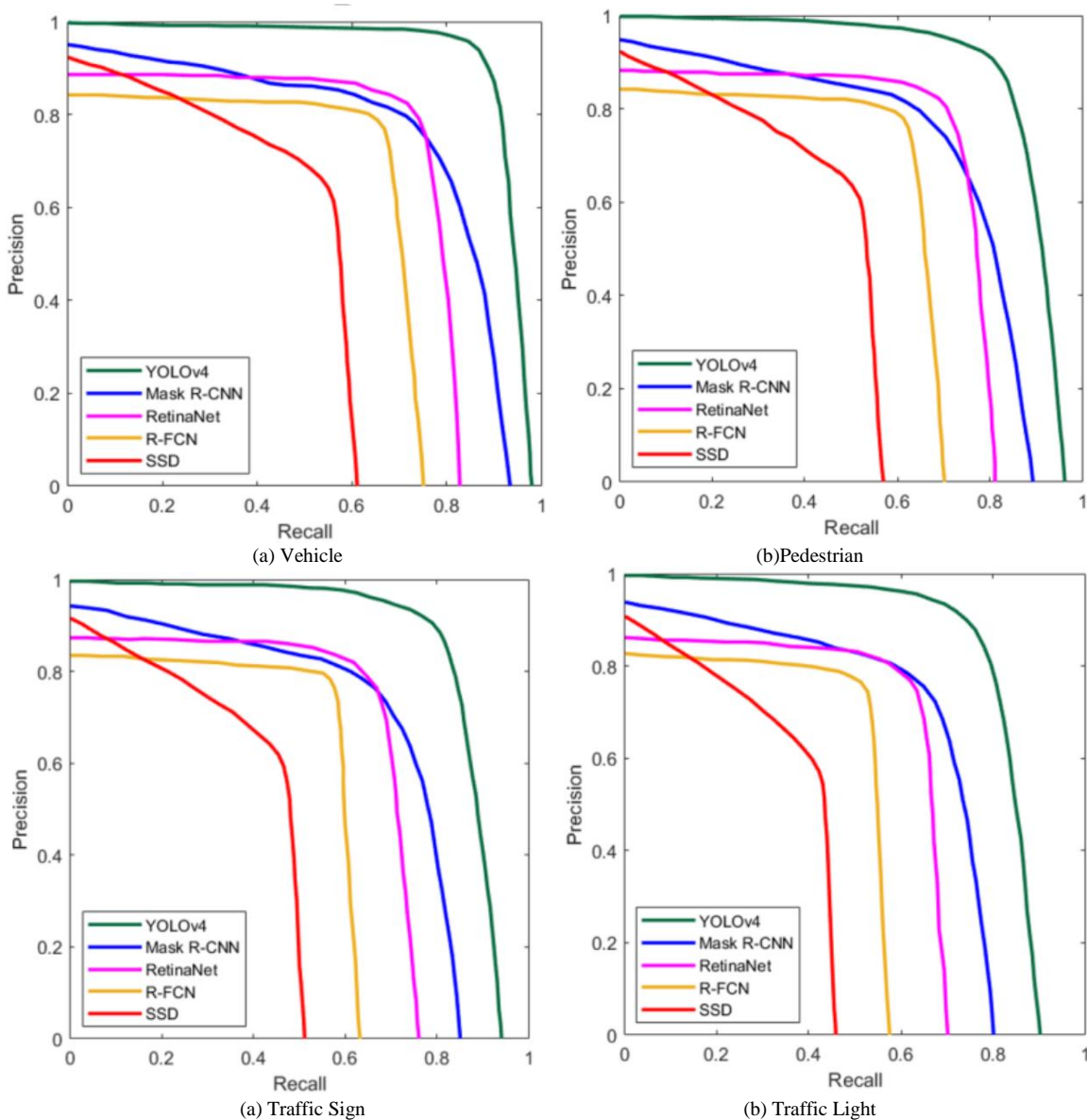
Fig. 5.    Precision-Recall (PR) curves of object detection models.

### B. Performance Analysis of Yolo-based Object Detectors

In this section, inspired from [29], the performance of YOLO object detection models on different CPU and GPU architectures is investigated. For this comparison, YOLO base models are first explored on NVIDIA GPUs, including the TESLA P100, TESLA V100, GTX 1080Ti, and RTX 4090. The objective is to determine the fastest YOLO model for each GPU, considering factors such as speed and efficiency. This analysis will provide valuable insights for selecting the most appropriate YOLO model based on specific hardware configurations and real-world application requirements.

The YOLO models are designed for real-time object detection and rely on dividing the input image into a grid, predicting bounding boxes and class probabilities for each grid cell. Different versions of YOLO, such as YOLOv5, YOLOv6, and YOLOv7, offer trade-offs between speed and accuracy. The Nano and Tiny variants prioritize lightweight and faster performance, while larger versions like YOLOv7 provide higher accuracy at the cost of slightly reduced speed. By comparing the performance of these models on the specified NVIDIA GPUs, it is possible to identify the fastest model for each GPU, aiding in the selection of the optimal YOLO model based on the desired balance between speed, accuracy, and specific hardware requirements.

As shown in Fig. 6, the graph provides information on the performance of different YOLO (You Only Look Once) models on various GPU devices. Based on the data presented, we can discuss the better method in terms of speed and throughput.

Firstly, from the graph, it is evident that YOLOv5 Nano performs the best in terms of speed on the RTX 4090 GPU and TESLA P100. This indicates that if the primary concern is achieving the highest frames per second (FPS) for real-time object detection, YOLOv5 Nano would be the preferred choice. Secondly, YOLOv7 Tiny stands out as the model that provides the highest throughput on the GTX 1080 Ti and TESLA V100. Throughput refers to the number of objects detected per unit of time, and YOLOv7 Tiny excels in this aspect on these specific GPU devices. This is particularly beneficial in scenarios where accurately detecting a larger number of objects is more important than achieving the highest FPS.

On the other hand, the YOLOv6 Nano and Tiny models, while not performing at the same FPS as YOLOv5 and YOLOv7, are still not considered very slow. Although the graph does not provide specific data on their performance, it suggests that these models strike a balance between speed and accuracy. They may be a suitable choice when moderate speed is desired while still achieving satisfactory object detection results.

In conclusion, the better method depends on the specific requirements of the task at hand. YOLOv5 Nano is ideal for real-time applications where achieving the highest FPS is crucial. YOLOv7 Tiny excels in scenarios where high throughput is prioritized over real-time performance. Meanwhile, YOLOv6 Nano and Tiny models offer a compromise between speed and accuracy, making them a viable option in cases where moderate speed is desired without sacrificing too much on detection quality.

As shown in Fig. 7, in the CPUs platform, the YOLOv5 Nano models, specifically the P5, are expected to provide the highest speed. These models can achieve real-time frames per second (FPS) performance, surpassing 30 FPS. This means that they can process and analyze images or video streams in real-time, providing quick object detection results. The YOLOv5 Nano models are optimized for efficiency and speed, making them well-suited for consumer-grade CPUs where real-time performance is a priority.

On the other hand, the YOLOv7 Tiny model, while still capable of real-time object detection, operates at a slightly lower speed compared to the YOLOv5 Nano models. It typically runs at around 20 FPS, which is still quite impressive and suitable for many real-time applications. Although it may not match the speed of the YOLOv5 Nano models, the YOLOv7 Tiny model strikes a balance between speed and accuracy. It provides satisfactory results while ensuring efficient processing on general consumer CPUs.
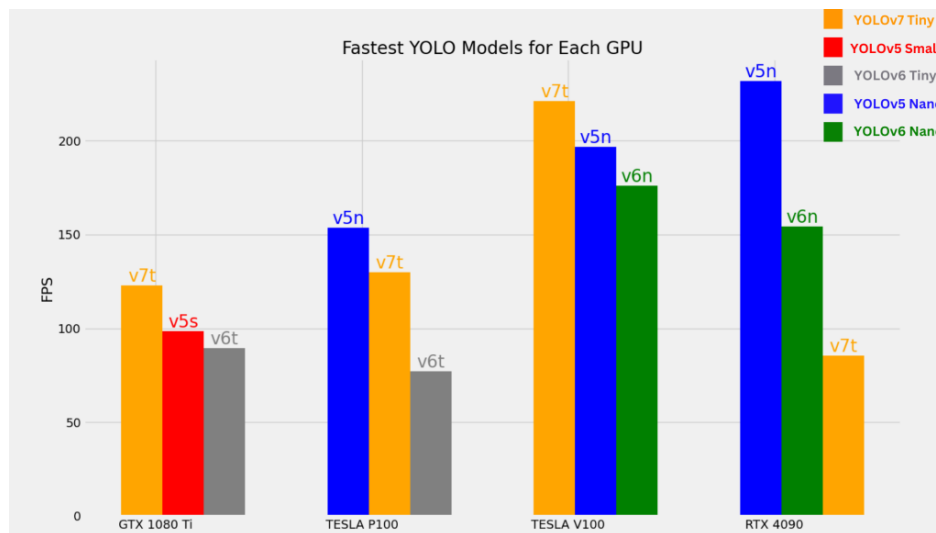


Fig. 6.    The fastest YOLO models on each GPU platform [29].
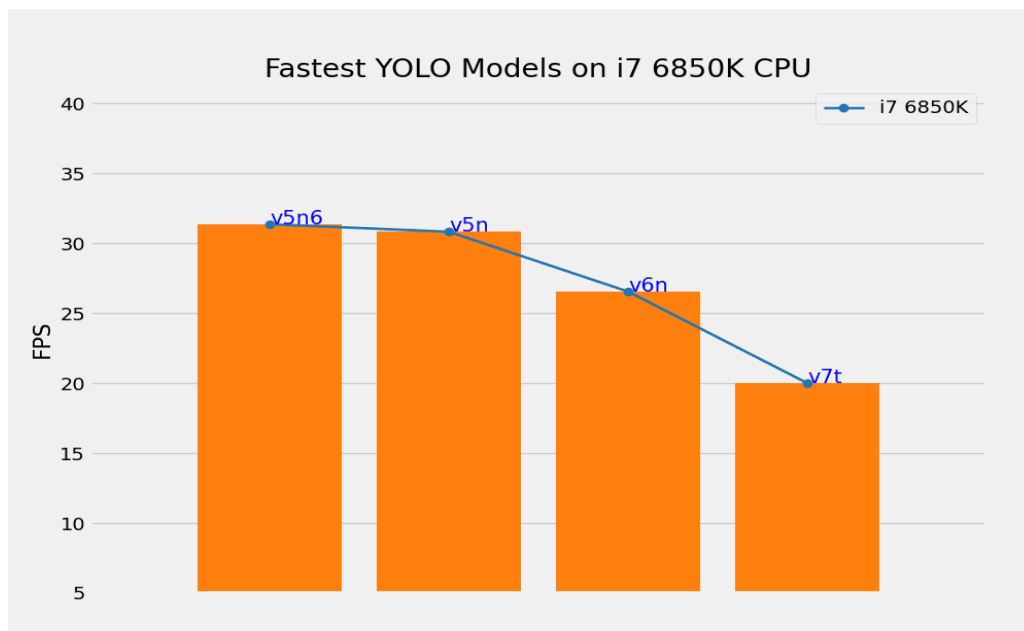
Fig. 7.   The four fastest YOLO object detection models on the i7 6850K CPU.

In conclusion, as a result shown, regardless of the specific CPU architecture, it observed that smaller models tend to exhibit faster performance. This is evident in these findings, where the YOLOv5 Nano and Nano P6 models emerged as the fastest options. Remarkably, even on an older generation i7 CPU, these models were able to achieve impressive speeds of over 30 frames per second (FPS). This demonstrates the efficiency and optimization of the YOLOv5 Nano and Nano P6 models for CPU processing, making them excellent choices for real-time object detection on consumer-grade CPUs.

## V.    CONCLUSION

This study conducted a thorough and comprehensive analysis of deep learning methods for object detection, focusing specifically on both two-stage and one-stage approaches. The main objective of this study is to identify the most superior algorithms in this domain and provide valuable insights into their unique strengths, limitations, and overall performance. It placed particular emphasis on comparing and contrasting the YOLO object detection models, including YOLOv5, YOLOv6, and YOLOv7, with respect to their frames per second (FPS) and accuracy. To ensure the reliability of our results, this study performed experiments using various NVIDIA GPU models such as GTX, RTX, and TESLA. This multi-platform evaluation allowed us to establish a solid foundation for this analysis and draw meaningful comparisons between the different YOLO versions. The findings from the study contribute to a better understanding of deep learning methods in object detection, enabling researchers and practitioners to make informed decisions when selecting the most suitable algorithms for their specific requirements. For future works, one potential future research direction is to investigate the fusion of two-stage and one-stage object detection algorithms to leverage their respective strengths and improve overall performance. Another promising avenue for future work is the adaptation of object detection algorithms for edge computing, aiming to optimize models for resource-constrained edge devices and enable real-time object detection at the network edge.

## REFERENCES

[1]   Y. Bai, B. Zhang, N. Xu, J. Zhou, J. Shi, and Z. Diao, "Vision-based navigation and guidance for agricultural autonomous vehicles and robots: A review," Computers and Electronics in Agriculture, vol. 205, p. 107584, 2023.

[2]   P. Shubham and V. Begishev, "Exploration of Autonomous Vehicles in Smart City Environment," EasyChair, 2516-2314, 2023.

[3]   M. A. Richter, M. Hagenmaier, O. Bandte, V. Parida, and J. Wincent, "Smart cities, urban mobility and autonomous vehicles: How different cities needs different sustainable investment strategies," Technological Forecasting and Social Change, vol. 184, p. 121857, 2022.

[4]   A. Balasubramaniam and S. Pasricha, "Object detection in autonomous vehicles: Status and open challenges," arXiv preprint arXiv:2201.07706, 2022.

[5]   N. M. A. A. Dazlee, S. A. Khalil, S. Abdul-Rahman, and S. Mutalib, "Object detection for autonomous vehicles with sensor-based technology using yolo," International Journal of Intelligent Systems and Applications in Engineering, vol. 10, no. 1, pp. 129-134, 2022.

[6]   S. Liang et al., "Edge YOLO: Real-time intelligent object detection system based on edge-cloud cooperation in autonomous vehicles," IEEE Transactions on Intelligent Transportation Systems, vol. 23, no. 12, pp. 25345-25360, 2022.

[7]   Y. Peng, Y. Qin, X. Tang, Z. Zhang, and L. Deng, "Survey on image and point-cloud fusion-based object detection in autonomous vehicles," IEEE Transactions on Intelligent Transportation Systems, vol. 23, no. 12, pp. 22772-22789, 2022.

[8]   V. S. R. Kosuru and A. K. Venkitaraman, "Preventing the False Negatives of Vehicle Object Detection in Autonomous Driving Control Using Clear Object Filter Technique," in 2022 Third International Conference on Smart Technologies in Computing, Electrical and Electronics (ICSTCEE), 2022: IEEE, pp. 1-6.

[9]   T. Sharma, B. Debaque, N. Duclos, A. Chehri, B. Kinder, and P. Fortier, "Deep learning-based object detection and scene perception under bad weather conditions," Electronics, vol. 11, no. 4, p. 563, 2022.

[10]  S. Iftikhar, Z. Zhang, M. Asim, A. Muthanna, A. Koucheryavy, and A. A. Abd El-Latif, "Deep Learning-Based Pedestrian Detection in

Autonomous Vehicles: Substantial Issues and Challenges," Electronics, vol. 11, no. 21, p. 3551, 2022.

[11] S. Alaba, A. Gurbuz, and J. Ball, "A comprehensive survey of deep learning multisensor fusion-based 3d object detection for autonomous driving: Methods, challenges, open issues, and future directions," 2022.

[12] X. Ma, W. Ouyang, A. Simonelli, and E. Ricci, "3D object detection from images for autonomous driving: a survey," arXiv preprint arXiv:2202.02980, 2022.

[13] T. Diwan, G. Anirudh, and J. V. Tembhurne, "Object detection using YOLO: Challenges, architectural successors, datasets and applications," multimedia Tools and Applications, vol. 82, no. 6, pp. 9243-9275, 2023.

[14] L. Du, R. Zhang, and X. Wang, "Overview of two-stage object detection algorithms," in Journal of Physics: Conference Series, 2020, vol. 1544, no. 1: IOP Publishing, p. 012033.

[15] M. Carranza-García, J. Torres-Mateo, P. Lara-Benítez, and J. García-Gutiérrez, "On the performance of one-stage and two-stage object detectors in autonomous vehicles using camera data," Remote Sensing, vol. 13, no. 1, p. 89, 2020.

[16] N. Jain, S. Yerragolla, and T. Guha, "Performance Analysis of Object Detection and Tracking Algorithms for Traffic Surveillance Applications using Neural Networks," in 2019 Third International conference on I-SMAC (IoT in Social, Mobile, Analytics and Cloud)(I-SMAC), 2019: IEEE, pp. 690-696.

[17] E. Güney, C. Bayilmiş, and B. Çakan, "An implementation of real-time traffic signs and road objects detection based on mobile GPU platforms," Ieee Access, vol. 10, pp. 86191-86203, 2022.

[18] B. Mahaur, N. Singh, and K. Mishra, "Road object detection: a comparative study of deep learning-based algorithms," Multimedia Tools and Applications, vol. 81, no. 10, pp. 14247-14282, 2022.

[19] B. Mahaur and K. Mishra, "Small-object detection based on YOLOv5 in autonomous driving systems," Pattern Recognition Letters, vol. 168, pp. 115-122, 2023.

[20] J. Dai, Y. Li, K. He, and J. Sun, "R-fcn: Object detection via region-based fully convolutional networks," Advances in neural information processing systems, vol. 29, 2016.

[21] K. He, G. Gkioxari, P. Dollár, and R. Girshick, "Mask RCNN. 2017 IEEE International Conference on Computer Vision," 2017.

[22] M. Peker, "Comparison of tensorflow object detection networks for licence plate localization," in 2019 1st Global Power, Energy and Communication Conference (GPECOM), 2019: IEEE, pp. 101-105.

[23] H. Jung, B. Lodhi, and J. Kang, "An automatic nuclei segmentation method based on deep convolutional neural networks for histopathology images," BMC Biomedical Engineering, vol. 1, no. 1, pp. 1-12, 2019.

[24] W. Liu, D. Anguelov, D. Erhan, C. Szegedy, S. Reed, C.-Y. Fu, and A. C. Berg, "Ssd: Single shot multibox detector," in Computer Vision–ECCV 2016: 14th European Conference, Amsterdam, The Netherlands, October 11–14, 2016, Proceedings, Part I 14, 2016: Springer, pp. 21-37.

[25] T.-Y. Lin, P. Goyal, R. Girshick, K. He, and P. Dollár, "Focal loss for dense object detection," in Proceedings of the IEEE international conference on computer vision, 2017, pp. 2980-2988.

[26] A. Bochkovskiy, C.-Y. Wang, and H.-Y. M. Liao, "Yolov4: Optimal speed and accuracy of object detection," arXiv preprint arXiv:2004.10934, 2020.

[27] M. Bahaghighat, Q. Xin, S. A. Motamedi, M. M. Zanjireh, and A. Vacavant, "Estimation of wind turbine angular velocity remotely found on video mining and convolutional neural network," Applied Sciences, vol. 10, no. 10, p. 3544, 2020.

[28] C. Liu, Y. Tao, J. Liang, K. Li, and Y. Chen, "Object detection based on YOLO network," in 2018 IEEE 4th information technology and mechatronics engineering conference (ITOEC), 2018: IEEE, pp. 799-803.

[29] V. G. Sovit Rath. Performance Comparison of YOLO Object Detection Models – An Intensive Study [Online] Available: https://learnopencv.com/performance-comparison-of-yolo-models/

# A Survey of Structural Health Monitoring Advances Based on Internet of Things (IoT) Sensors

Hao DENG, JianHua CHEN

Chongqing Industry Polytechnic College, Chongqing 401120, China

*Abstract*—**Structural Health Monitoring (SHM) is a technique that ensures the safety and reliability of structures through continuous and real-time monitoring. IoT-based sensors have become a popular solution for implementing SHM systems, and research in this area is essential for improving the accuracy and reliability of SHM systems. A review of the current state-of-the-art is necessary to identify the challenges and opportunities for further development of SHM systems based on IoT sensors. This study presents a survey to comprehensively review of SHM, focusing on IoT sensors. Secondly, the categorization of the current civil structural monitoring methods is established, and the advantages and disadvantages of the methods are addressed. Thirdly, an analysis is performed, and the result is compared to civil structural monitoring methods. Finally, key features of the methods are discussed and summarized, and at last, some directions for future studies are presented.**

*Keywords*—*Structural health monitoring; civil structures; internet of things; sensors; survey*

## I. INTRODUCTION

Structural monitoring is especially critical for aging infrastructure, which can suffer from wear and tear over time [1, 2]. By detecting early signs of damage or deterioration, it is possible to implement repairs or replacements before more extensive damage occurs [3, 4]. This can help prevent catastrophic failures and ensure the safety of the public and infrastructure workers. Structural Health Monitoring (SHM) is a method that facilitates the continuous and real-time monitoring of various structures such as bridges, buildings, and pipelines [5, 6]. SHM systems employ different sensors and technologies to detect structural damages or defects. This allows for timely repair or maintenance, thus avoiding catastrophic failures [7]. In civil engineering, SHM plays a critical role in ensuring the safety and reliability of important infrastructure.

Advancements in SHM systems have the potential to enhance the longevity, safety, and sustainability of structures, resulting in significant social and economic benefits [8]. Consequently, SHM has become a significant research area in this field and other civil structures [4, 9]. The goal of structural monitoring is to identify early signs of damage or deterioration and assess the structural integrity of the infrastructure to ensure safety and longevity [10, 11]. Many techniques and technologies are used in civil structural monitoring, including sensors, cameras, and other monitoring equipment [12, 13]. The data collected from these devices is often analyzed using machine learning algorithms to identify patterns and detect anomalies [14].

The integration of Internet of Things (IoT) technology with SHM systems allows for remote and real-time monitoring of structures, providing valuable data that can be analyzed to detect any damage or defects [15]. IoT-based SHM systems use various sensors and devices that can detect environmental conditions, vibrations, and strains in the structures, allowing for timely maintenance or repair before a failure occurs [16]. This approach has the potential to significantly improve the accuracy and reliability of SHM systems, making it an exciting and promising area of research in the field of civil engineering.

This study presents a comprehensive overview of SHM using IoT sensors. Section II deals with the categorization of the current civil structural monitoring methods is established, and the advantages and disadvantages of the methods are addressed. In Section III, an analysis is performed, and the result is compared to civil structural monitoring methods. Section IV presents key features of the methods are discussed and summarized, and finally conclusion of this paper and some directions for future studies are presented in Section V and Section VI, respectively.

The uniqueness of this paper, when compared to the review of the literature, lies in its multifaceted approach to Structural Health Monitoring (SHM) with a specific focus on IoT sensors. While the existing literature provides some insights into SHM, this study goes beyond by not only offering a comprehensive overview but also categorizing the current civil structural monitoring methods. By addressing the advantages and disadvantages of these methods and conducting a detailed comparative analysis, this paper provides a more in-depth understanding of the state-of-the-art in SHM based on IoT sensors. Furthermore, the paper concludes by presenting key features and directions for future research, adding a forward-looking dimension that sets it apart from a mere literature review.

## II. RELATED WORKS

This section presents a review of previous studies on structural health monitoring with the covering of IoT-based sensors. Tokognon et al. [15] presented a comprehensive survey of the existing literature on Structural Health Monitoring (SHM) frameworks based on the Internet of Things (IoT). The authors discuss the importance of SHM and how IoT technologies can be used to enhance SHM systems. They review the various IoT-based sensors and devices that can be used for SHM and the different techniques for data collection and analysis. The authors also identify the challenges and limitations of IoT-based SHM systems and the potential solutions to address them. Overall, this paper provides a

valuable resource for researchers and practitioners working on IoT-based SHM systems, highlighting the current state-of-the-art and future research directions in this field.

Ye et al. [17] provided a comprehensive review of the recent developments in deep learning-based structural health monitoring (SHM) of civil infrastructures. The paper discusses the benefits of using deep learning techniques, such as artificial neural networks and convolutional neural networks, for SHM applications and reviews the different types of deep learning models that have been developed for civil infrastructure monitoring. The authors also provide case studies of deep learning-based SHM in various civil infrastructure projects, demonstrating the potential of these techniques in improving the accuracy and efficiency of SHM. Overall, the paper is a valuable resource for researchers, engineers, and practitioners working in the field of SHM and civil infrastructure, especially those interested in applying deep learning techniques to enhance the reliability and safety of civil structures.

Mishra et al. [18] presented an overview of the use of the Internet of Things (IoT) for structural health monitoring (SHM) of civil engineering structures. The authors discuss the benefits and challenges associated with using IoT technologies for SHM, including improved data collection, analysis, and communication. The paper also provides case studies of IoT-based SHM in different civil engineering structures, demonstrating the potential benefits of these technologies in improving the safety and reliability of civil engineering structures. Overall, the paper is a useful resource for researchers, engineers, and practitioners working in the field of civil engineering and structural health monitoring.

A survey of the recent developments in fiber-optic sensing technologies was presented for structural health monitoring (SHM) of civil infrastructure by Wu et al. [19]. The paper discusses the benefits of fiber-optic sensors, including their sensitivity, durability, and resistance to electromagnetic interference, and reviews different types of fiber-optic sensors that have been developed for SHM applications. The authors also provide case studies of fiber-optic sensor applications in various civil infrastructure projects, demonstrating the potential of these sensors in improving the safety and reliability of civil infrastructure. Overall, the paper is a valuable resource for researchers, engineers, and practitioners working in the field of SHM and civil infrastructure.

Malekloo et al. [20] presented a comprehensive overview of machine learning (ML) techniques for structural health monitoring (SHM) applications, with a focus on emerging technologies and high-dimensional data sources. The paper discusses the benefits of using ML techniques, such as support vector machines and random forests, for SHM applications and reviews different types of ML models that have been developed for civil infrastructure monitoring. The authors also highlight the importance of using emerging technologies, such as unmanned aerial vehicles and wireless sensor networks, to enhance the effectiveness of ML-based SHM. The paper provides case studies of ML-based SHM in various civil infrastructure projects, demonstrating the potential of these techniques in improving the accuracy and efficiency of SHM. Overall, the paper is a valuable resource for researchers, engineers, and practitioners working in the field of SHM and civil infrastructure, especially those interested in applying ML techniques to enhance the reliability and safety of civil structures.

An overview of the subspace system identification (SSI) method was presented for the health monitoring of civil infrastructures by Shokravi et al. [21]. The paper discusses the benefits of using the SSI method for SHM applications, such as its ability to identify system parameters accurately and detect damage in civil infrastructures. The authors provide case studies of SSI-based SHM in various civil infrastructure projects, demonstrating the potential of this method in improving the accuracy and efficiency of SHM. Overall, the paper is a valuable resource for researchers, engineers, and practitioners working in the field of SHM and civil infrastructure, especially those interested in applying the SSI method to enhance the reliability and safety of civil structures.

## III. STRUCTURAL HEALTH MONITORING TECHNOLOGIES

Various types of monitoring methods are available, including visual inspections, non-destructive testing, and structural health monitoring using sensors, among others. Each method has its strengths and limitations, and the selection of a monitoring method depends on factors such as the type of structure, its location, and the available resources. Fig. 1 shows the categorization of civil structural monitoring methods.

### A. Visual Inspections

Visual inspections are one of the most common methods used in civil structural monitoring to assess the condition of a structure [22]. The visual inspection is used computer vision algorithms to extract useful information from the images and videos [41]. This method involves the visual examination of a structure's surface and other visible components to identify signs of damage or degradation. Visual inspections can be conducted by trained professionals or by using automated technologies such as drones equipped with cameras [23, 24]. Table I presents visual inspection methods used for civil structural monitoring.

### B. Structural Health Monitoring (SHM)

The SHM is a method of continuously monitoring a structure's condition to detect any signs of damage or degradation [5]. SHM involves the use of sensors to measure various parameters such as strain, vibration, temperature, and displacement, which are then analyzed to assess the structure's condition [25]. SHM can help to identify potential problems before they become serious, allowing for timely repairs and maintenance to be performed [26]. Table II presents the Infrared SHM used for civil structural monitoring.
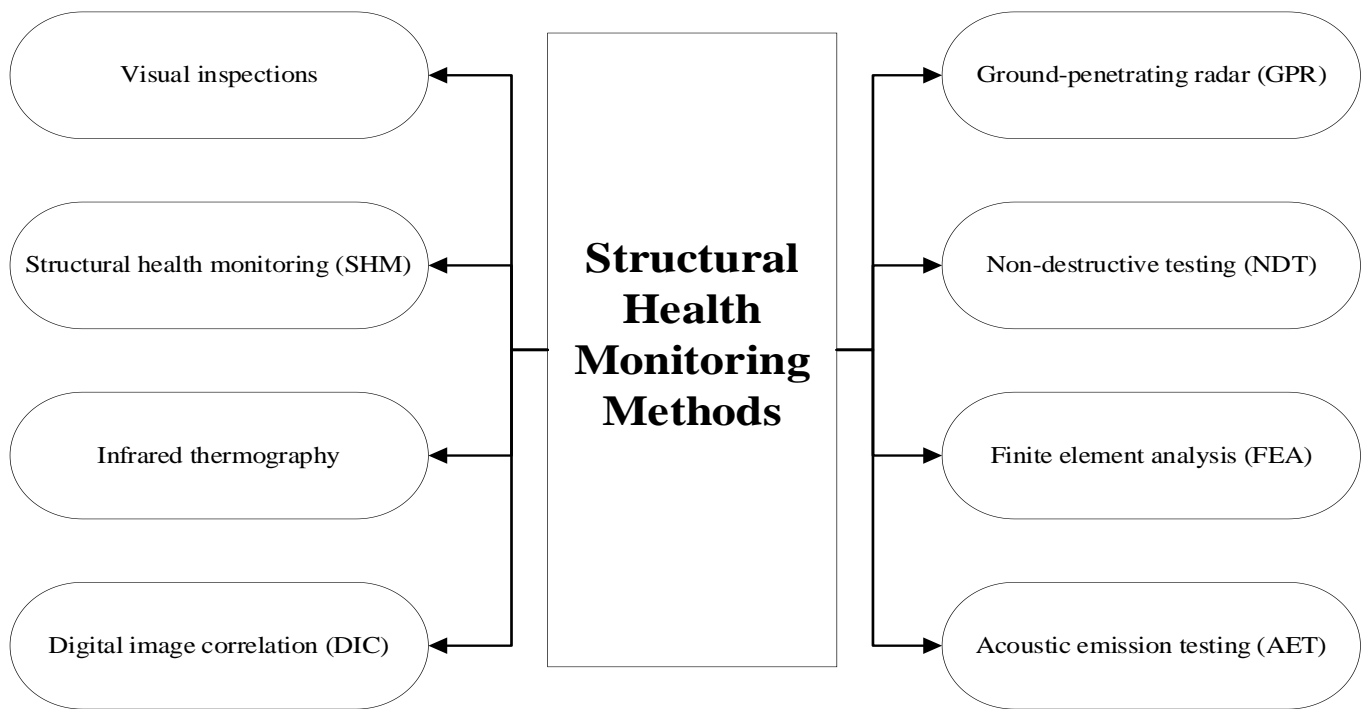
Fig. 1. Categorization of civil structural monitoring methods.

TABLE I. THE VISUAL INSPECTION METHODS USED FOR CIVIL STRUCTURAL MONITORING

| Method | Description | Pros | Cons |
|---|---|---|---|
| Bridge inspection using unmanned aerial vehicles (UAVs) | Inspection of bridges using UAVs equipped with high-resolution cameras | Non-intrusive can access hard-to-reach areas | Limited ability to detect internal damage |
| Crack detection using digital image correlation (DIC) | Detection of cracks and deformations using high-resolution cameras and computer vision algorithms | High accuracy, non-intrusive | Limited to surface damage |
| Tunnel lining inspection using LiDAR | Inspection of tunnel linings using LiDAR scanners | Rapid data collection, accurate mapping of interior surfaces | Limited ability to detect internal damage |
| Corrosion detection using electrochemical techniques | Detection of corrosion on metal structures using electrochemical sensors | Highly sensitive can detect early-stage corrosion | Limited to metal structures |
| Building facade inspection using drones | Inspection of building facades using drones equipped with high-resolution cameras | Non-intrusive can access hard-to-reach areas | Limited to surface damage |

TABLE II. THE SHM METHODS USED FOR CIVIL STRUCTURAL MONITORING

| Method | Description | Pros | Cons |
|---|---|---|---|
| Fiber optic sensors | Sensors that use light to measure strain and temperature | High accuracy, non-intrusive | Expensive, require specialized installation |
| Wireless sensor networks | Networks of sensors that communicate wirelessly to a central monitoring system | Real-time monitoring, easy installation | Limited range, may require battery replacement |
| Piezoelectric sensors | Sensors that measure mechanical stress using electric charge | High sensitivity can detect damage at early stages | Limited to certain types of structures |
| Acoustic emission sensors | Sensors that detect and analyze acoustic signals emitted by structures | Non-intrusive can detect damage at early stages | Limited to certain types of structures |
| Electrochemical corrosion sensors | Sensors that detect corrosion on metal structures using electrochemical reactions | Highly sensitive can detect early-stage corrosion | Limited to metal structures |

TABLE III.    THE INFRARED THERMOGRAPHY METHODS USED FOR CIVIL STRUCTURAL MONITORING

| Method | Description | Pros | Cons |
|---|---|---|---|
| Building envelope inspection using Infrared thermography | Inspection of building envelopes to detect heat loss and insulation issues | Non-intrusive can detect hidden damage | Limited to surface damage |
| Concrete inspection using Infrared thermography | Inspection of concrete structures to detect internal defects such as voids and delamination | Non-intrusive can detect internal damage | Limited to certain types of structures |
| Bridge inspection using Infrared thermography | Inspection of bridges to detect delamination and corrosion on the surface | Non-intrusive can detect hidden damage | Limited to surface damage |
| Electrical equipment inspection using Infrared thermography | Inspection of electrical equipment to detect overheating and potential electrical faults | Non-intrusive can detect hidden damage | Limited to electrical equipment |

## C. Infrared Thermography

Infrared thermography is a method of detecting changes in temperature on a structure's surface to identify potential defects or damage [27, 28]. This method involves the use of infrared cameras to capture thermal images, which can then be analyzed to identify areas of the structure with abnormal temperature patterns [29]. Infrared thermography can be used to identify defects such as water infiltration, heat loss, and insulation issues [30]. Table III presents the Infrared thermography methods used for civil structural monitoring.

## D. Digital Image Correlation (DIC)

Digital image correlation (DIC) is a non-destructive testing method that uses digital images to measure the deformation and strain of a structure [31, 32]. This method involves capturing images of the structure at different intervals during loading and then using specialized software to analyze the images and determine the deformation and strain. Table IV presents the DIC methods used for civil structural monitoring.

## E. Ground-penetrating Radar (GPR)

Ground-penetrating radar (GPR) is a non-destructive testing method that uses electromagnetic waves to detect and map features within structures and materials [33, 34]. This method involves transmitting a high-frequency electromagnetic pulse into the structure or material and measuring the reflections and diffractions that occur as the pulse travels through it. Table V presents the GPR methods used for civil structural monitoring.

## F. Non-destructive Testing (NDT)

Non-destructive testing (NDT) methods are techniques that allow for the assessment of the condition of civil infrastructure without causing damage to the structure [35, 36]. Table VI presents popular existing NDT methods used for civil structural monitoring.

TABLE IV.    THE DIC METHODS USED FOR CIVIL STRUCTURAL MONITORING

| Method | Description | Pros | Cons |
|---|---|---|---|
| Bridge load testing using digital image correlation | Testing the load-carrying capacity of bridges using DIC | Non-intrusive can provide accurate data | Limited to certain types of structures |
| Concrete deformation measurement using digital image correlation | Measuring the deformation and strain of concrete structures | Non-intrusive, high accuracy | Limited to surface measurements |
| Structural deformation measurement using digital image correlation | Measuring the deformation and strain of various types of structures | Non-intrusive can provide accurate data | Limited to surface measurements |
| Material testing using digital image correlation | Measuring the deformation and strain of materials under different loading conditions | Non-destructive can provide accurate data | Limited to laboratory conditions |

TABLE V.    THE GPR METHODS USED FOR CIVIL STRUCTURAL MONITORING

| Method | Description | Pros | Cons |
|---|---|---|---|
| Concrete inspection using ground-penetrating radar | Inspecting concrete structures for defects such as cracks and voids | Non-destructive can detect internal defects | Limited to certain types of structures |
| Detection of buried utilities using ground-penetrating radar | Detecting buried utilities such as pipes and cables | Non-destructive can provide accurate data | Limited to certain types of soils and materials |
| Assessment of pavement thickness using ground-penetrating radar | Measuring the thickness of pavement layers | Non-destructive can provide accurate data | Limited to certain types of pavements |
| Assessment of bridge decks using ground-penetrating radar | Detecting delamination and reinforcing steel within bridge decks | Non-destructive can provide accurate data | Limited to certain types of bridge decks |

TABLE VI.    THE NDT METHODS USED FOR CIVIL STRUCTURAL MONITORING

| Method | Description | Pros | Cons |
|---|---|---|---|
| Ultrasonic testing | Ultrasonic waves are transmitted into the structure, and the reflections are measured to detect defects such as cracks and voids. | Non-destructive can detect internal defects, highly accurate | Limited to certain types of structures, requires specialized equipment and training |
| Magnetic particle inspection | A magnetic field is applied to the structure, and magnetic particles are introduced to the surface. Any defects in the structure cause a disruption in the magnetic field, allowing them to be detected. | Non-destructive can detect surface and near-surface defects | Limited to ferromagnetic materials, may not detect small defects |
| Eddy current testing | An alternating current is applied to the structure, inducing eddy currents which generate a magnetic field. Any defects in the structure cause a disruption in the magnetic field, allowing them to be detected. | Non-destructive can detect surface and near-surface defects highly accurately. | Limited to conductive materials, may not detect small defects |

TABLE VII.    THE FEA METHODS USED FOR CIVIL STRUCTURAL MONITORING

| Method | Description | Pros | Cons |
|---|---|---|---|
| Static analysis | The structure is modeled as a system of linear equations which are solved to determine the stresses and deformations under static loads. | Highly accurate, can model a wide range of structures and loading conditions | Assumes linear behavior of materials, cannot account for dynamic effects |
| Dynamic analysis | The structure is modeled as a system of differential equations, which are solved to determine the response under dynamic loads such as earthquakes and wind. | It can account for dynamic effects, useful for assessing the risk of failure under extreme loading conditions. | It can be computationally intensive and requires accurate modeling of damping and material behavior |
| Fatigue analysis | The structure is modeled under cyclic loading conditions to predict the accumulation of damage over time. | Can predict the expected life of a structure under cyclic loading, useful for designing maintenance schedules | Requires accurate modeling of material behavior and loading conditions, may not account for all sources of damage |

TABLE VIII.    THE AET METHODS USED FOR CIVIL STRUCTURAL MONITORING

| Method | Description | Pros | Cons |
|---|---|---|---|
| Passive monitoring | AET sensors are installed on the structure to monitor for acoustic emissions continuously. | It can detect small or incipient damage, is non-invasive, and can monitor large areas. | Limited to detecting events with significant energy release, cannot pinpoint the location of the damage. |
| Active monitoring | AET is performed while the structure is under load or undergoing testing. | It can detect damage as it occurs and identify the location and extent of damage. | It may require access to the structure and may not be practical for continuous monitoring. |
| Source location | Multiple AET sensors are used to triangulate the location of acoustic emissions. | Can pinpoint the location of damage, useful for determining the extent of damage | It may require a large number of sensors, limited by the ability to detect signals in noisy environments. |

*G. Finite Element Analysis (FEA)*

Finite element analysis (FEA) is a computational method that uses numerical models to simulate the behavior of civil infrastructure under various loading conditions [37, 38]. Finite element analysis (FEA) is a computational method that uses numerical models to simulate the behavior of civil infrastructure under various loading conditions. Table VII shows some existing FEA methods used for civil structural monitoring.

*H. Acoustic Emission Testing (AET)*

Acoustic emission testing (AET) is a non-destructive testing (NDT) method that detects acoustic signals produced by the internal deformation of a material or structure [39, 40]. Table VIII presents popular AET methods used for civil structural monitoring.

IV.    ANALYSIS OF CIVIL STRUCTURAL MONITORING METHODS

In this study, the analysis of the methods is conducted through a meticulous examination of previous research and a thorough review of the data presented in the original papers. Our approach involves a comprehensive assessment aimed at identifying and elucidating the advantages and disadvantages of these methods. To ensure the accuracy and reliability of our analysis, we rely on the data reported in the original papers as our foundational source, supplemented by our own investigations. These investigations are carried out using standard performance metrics, allowing us to provide a rigorous and objective evaluation of the methods under consideration. This combined approach ensures a robust and well-informed analysis, contributing to the depth and credibility of our research findings. For this analysis qualitative and quantitative analysis are conducted, the detail of each discuss as follows,

## A. Qualitative Analysis

The qualitative analysis for the SHM method involves comparing different monitoring methods across several criteria to determine their effectiveness in detecting changes or damage in civil structures. These criteria include cost, ease of implementation, resolution, and range. By analyzing each method based on these criteria and assigning a numerical score, a comprehensive comparison can be made to identify the most suitable method for a specific application. The analysis uses data and information from previous studies and research, allowing for a data-driven approach to evaluating each method.

- Cost: The estimated cost associated with implementing the monitoring method. This includes equipment, labor, and any other expenses associated with the method.

- Ease of implementation: How difficult it is to set up and utilize the monitoring method. This takes into account factors such as the expertise required to operate the equipment, as well as any additional equipment needed to implement the method.

- Resolution: The level of detail that the monitoring method can provide in measuring changes or damage in the structure being monitored.

- Range: The distance from the structure that the monitoring method can effectively measure changes or damage. This takes into account the maximum effective range of the equipment used in the method.

Based on the performance analysis criteria, Table IX presents the performance analysis for civil structural monitoring methods.

According to Table IX, the cost of the different methods ranges from low to high, with visual inspections being the least expensive and SHM, NDT, and FEA being the most expensive. Ease of implementation ranges from easy to difficult, with visual inspections being the easiest and SHM and FEA being the most difficult. Sensitivity, accuracy, and resolution are all high for SHM, NDT, FEA, GPR, and DIC, while visual inspections and infrared thermography have lower values for these parameters. The range of each method varies from short to medium, with most methods being limited to the immediate vicinity of the structure. Overall, the choice of method will depend on the specific needs of the project, including the level of detail required, the available budget, and the location and accessibility of the structure.

## B. Quantitative Analysis

The quantitative analysis for Civil Structural Monitoring methods involves comparing different monitoring methods across several criteria to determine their effectiveness in detecting changes or damage in civil structures. For this analysis, image processing, machine learning and deep learning approaches are considered. In the following section, the quantitative analyses are conducted for these methods.

*1) Analysis of image processing methods:* In this analysis, the most popular image processing methods are analyzed. These methods involve Edge Detection, Thresholding, Morphological Operations, Region-based Segmentation, Contour Analysis, Texture Analysis, Template Matching, Hough Transform and Connected Component Analysis.

For this analysis, popular performance metrics are considered, which include precision, recall and F-score. The precision, recall and F-score values are typically calculated based on the true positive, false positive, and false negative rates. In this study, we collected the values from previously published research works. Fig. 2 demonstrates the analysis of image processing methods.

*2) Analysis of traditional machine learning methods:* For analysis of traditional machine learning methods, we selected the most used methods in the literature. These methods involve Support Vector Machines (SVM), Random Forests, k-Nearest Neighbors (k-NN), Decision Trees, Naive Bayes, Ensemble methods (AdaBoost), Logistic Regression, and Neural Networks.

Similar to image processing analysis, popular performance metrics are considered, including precision, recall and F-score. Fig. 3 demonstrates the analysis of image processing methods.

TABLE IX. PERFORMANCE ANALYSIS FOR CIVIL STRUCTURAL MONITORING METHODS

| Method | Cost | Ease of implementation | Resolution | Range |
|---|---|---|---|---|
| Visual inspections | Low | Easy | Low | Short |
| Structural health monitoring (SHM) | High | Difficult | High | Short to medium |
| Infrared thermography | Medium | Moderate | Medium | Short to medium |
| Digital image correlation (DIC) | Medium | Moderate | High | Short to medium |
| Ground-penetrating radar (GPR) | High | Moderate | Medium to high | Short to medium |
| Non-destructive testing (NDT) | High | Moderate to difficult | High | Short to medium |
| Finite element analysis (FEA) | High | Difficult | High | Short to medium |
| Acoustic emission testing (AET) | Medium to high | Moderate to difficult | High | Short to medium |
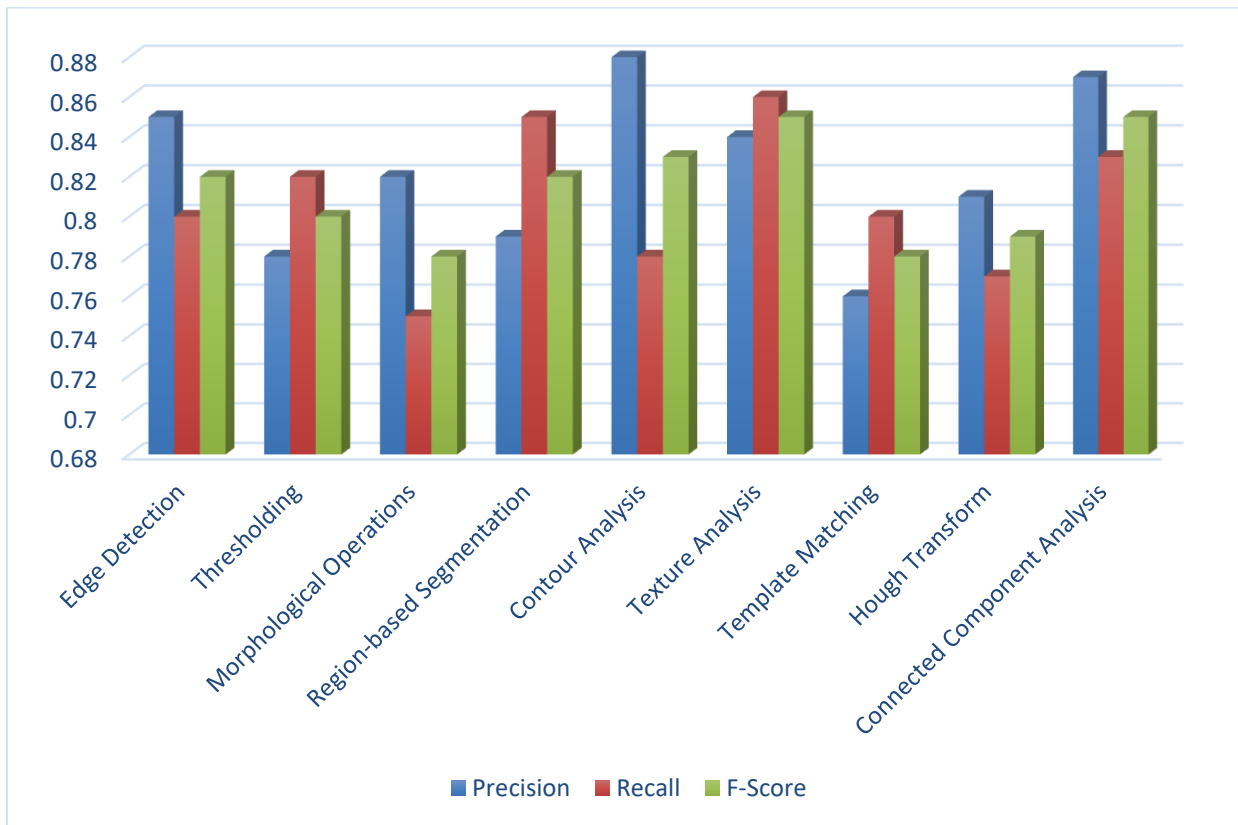
Fig. 2. Quantitative analysis of image processing methods.
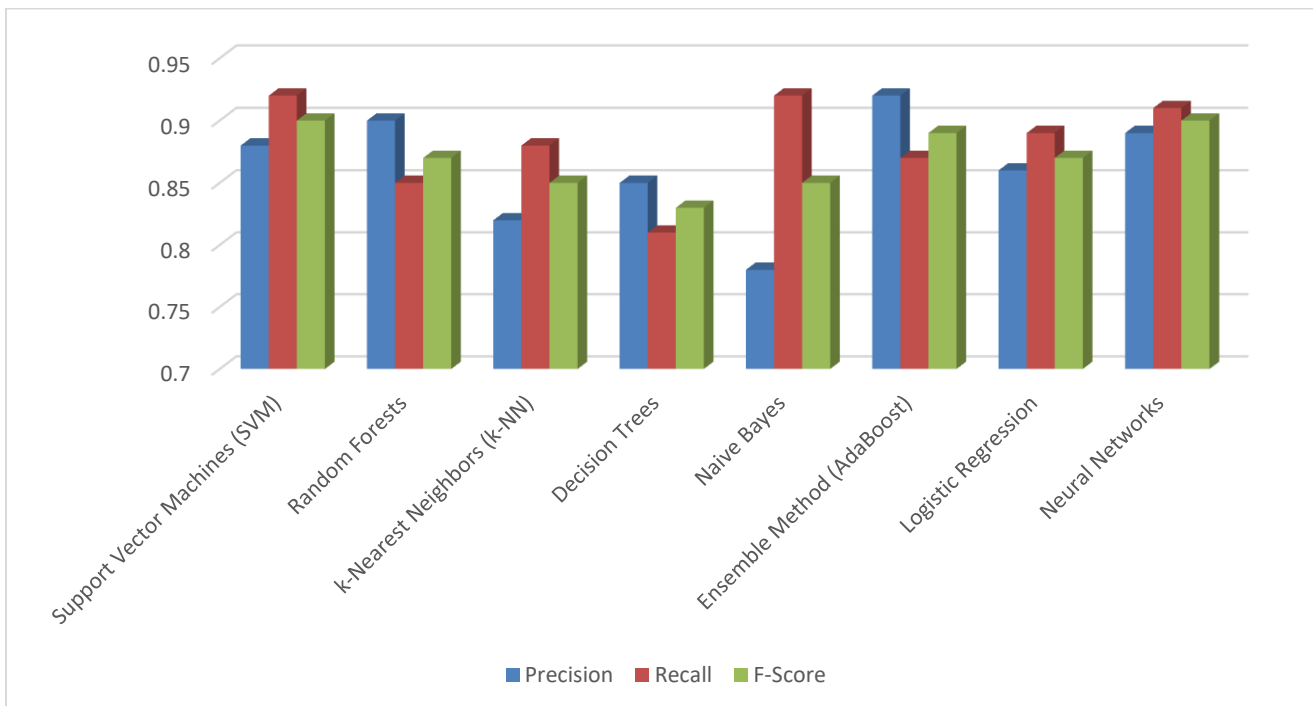


Fig. 3. Quantitative analysis of traditional machine learning methods.
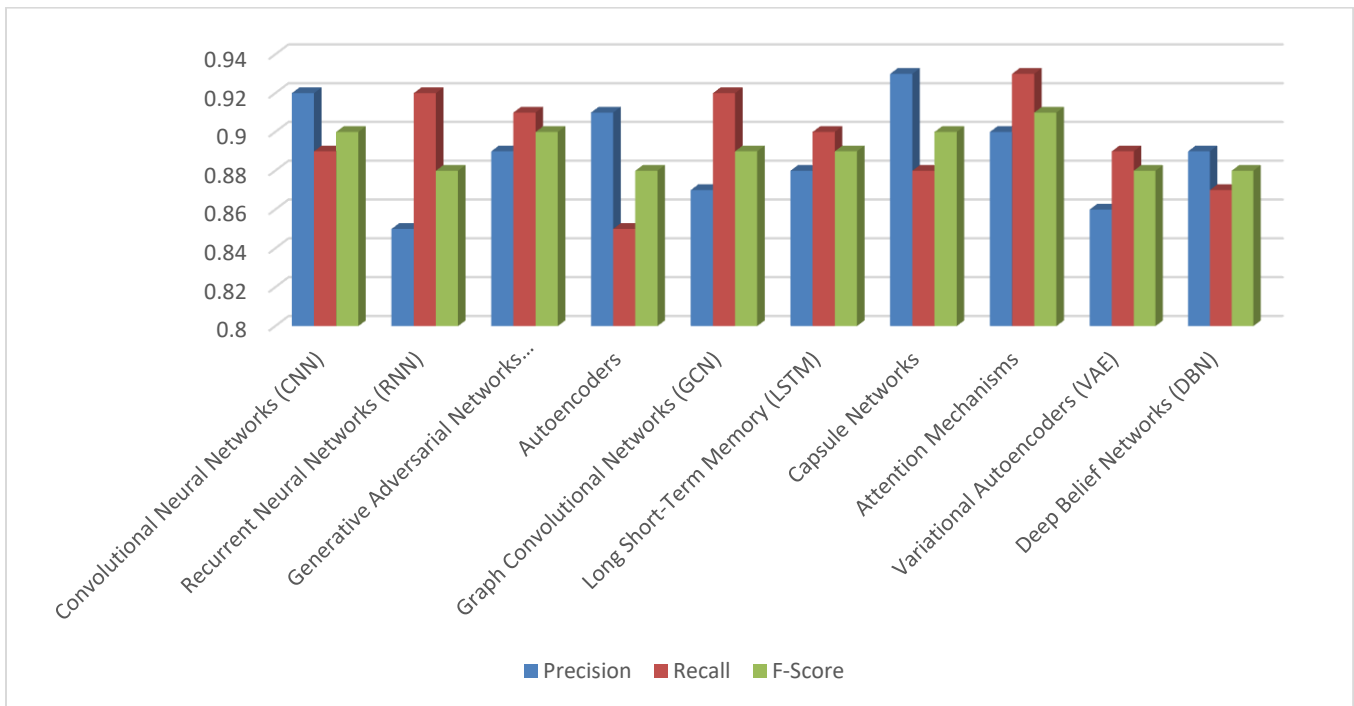
Fig. 4.    Quantitative analysis of deep learning methods.

*3) Analysis of deep learning methods:* For analysis of deep learning methods, we also selected the most used approaches in deep-based structural health monitoring systems. These methods involve Convolutional Neural Networks (CNN), Recurrent Neural Networks (RNN), Generative Adversarial Networks (GAN), Autoencoders, Graph Convolutional Networks (GCN), Long Short-Term Memory (LSTM), Capsule Networks, Attention Mechanisms, Variational Autoencoders (VAE), Deep Belief Networks (DBN).

Similar to image processing and machine learning analysis procedures, popular performance metrics include precision,

recall and F-score. Fig. 4 demonstrates the analysis of image processing methods.

*4) Comparison of the methods:* This section presents a comparison of performance measurements for image processing, machine learning and deep learning methods. Correspondingly, this comparison is conducted in terms of precision, recall and F-score. For this comparison, we calculated the average of precision, recall and F-score for each category of methods. Fig. 5 shows the comparison of the methods.
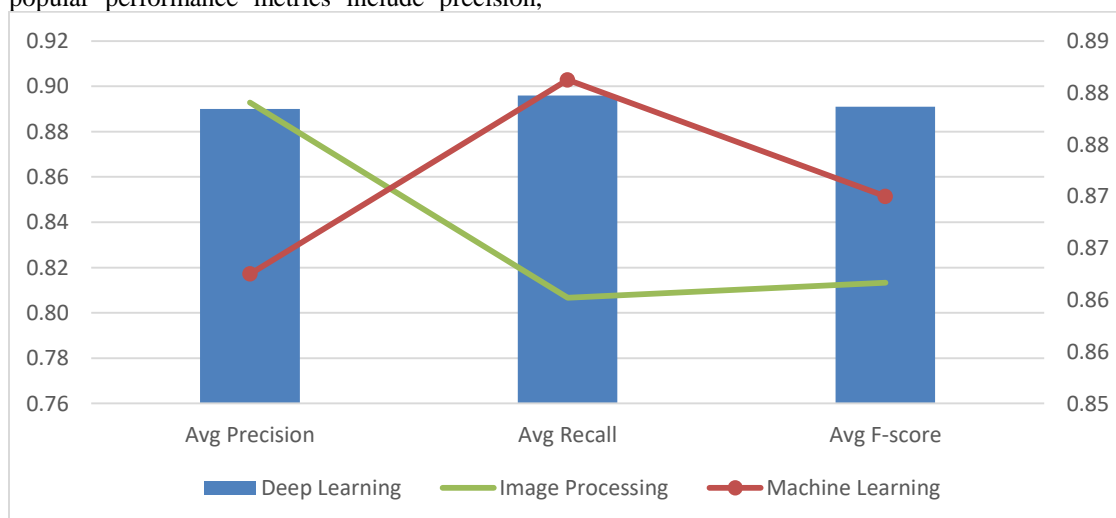


Fig. 5.    Average precision, recall and F-score for the methods.

## V. DISCUSSION

As discussed above, civil structural monitoring methods refer to techniques and approaches used to detect, monitor, and analyze changes in the behavior and condition of civil structures such as bridges, buildings, and tunnels. In the following, according to the evaluation and analysis section, the key features of the methods used are discussed.

The visual inspection method involves a visual examination of the structure, looking for signs of damage, deterioration, or deformation. It is a cost-effective method that does not require any special equipment, but it is subjective and dependent on the inspector's experience and expertise.

The Infrared thermography method uses thermal imaging cameras to detect changes in surface temperature caused by structural changes. It is non-destructive and can detect changes that are not visible to the naked eye, but it is sensitive to environmental factors such as sunlight and wind.

The DIC method uses two-dimensional images of the structure to detect changes in shape and deformation. It is a non-contact and non-destructive method that provides high-resolution data, but it requires specialized equipment and expertise.

The GPR method uses radar waves to detect changes in the composition and structure of the subsurface materials. It can detect voids, cracks, and other defects that are not visible to the naked eye, but it is dependent on the materials being scanned and can be affected by environmental factors such as moisture.

The FEA method uses computational modeling to simulate the behavior of a structure under different conditions. It is a highly detailed method that provides accurate data on the stresses and strains in the structure, but it requires specialized software and expertise.

The AET method uses sensors to detect high-frequency sounds generated by changes in the structure. It is a non-destructive and sensitive method that can detect changes in real-time, but it can be affected by environmental noise and requires specialized equipment.

## VI. CONCLUSION

This study has offered a comprehensive survey and review of Structural Health Monitoring (SHM) techniques, with a particular emphasis on the integration of IoT sensors. The categorization of existing civil structural monitoring methods has provided a valuable framework for understanding the landscape of monitoring methodologies. By critically assessing the advantages and disadvantages of these methods and conducting a comparative analysis, we have enhanced our insights into the current state-of-the-art in SHM, specifically concerning IoT-based sensors. This paper has underscored the importance of method selection in civil structural monitoring, with each approach having distinct merits and limitations tailored to specific structural requirements and monitoring objectives. The unique contribution of this study lies in its multifaceted approach, combining literature review, categorization, and comparative analysis, to offer a more comprehensive perspective on SHM. there are several promising directions for future research in the field of

Structural Health Monitoring. First, the integration of emerging technologies such as machine learning and artificial intelligence into IoT-based monitoring systems could significantly enhance the accuracy and efficiency of SHM techniques. Investigating these innovative approaches holds great potential for advancing the field. Additionally, further exploration of interdisciplinary applications of SHM, such as its utilization in disaster resilience and predictive maintenance, could expand its practical utility. Moreover, research into the development of cost-effective and scalable IoT sensor networks for large-scale infrastructure monitoring is an area that warrants attention. Finally, investigations into the long-term durability and reliability of IoT sensor deployments in real-world scenarios would contribute valuable insights to ensure the sustainability of SHM systems. These future directions have the potential to shape the evolution of Structural Health Monitoring, making it an even more robust and indispensable tool in ensuring the safety and integrity of civil structures.

## REFERENCES

[1] K. A. Eltouny and X. Liang, "Large - scale structural health monitoring using composite recurrent neural networks and grid environments," Computer - Aided Civil and Infrastructure Engineering, vol. 38, no. 3, pp. 271-287, 2023.

[2] H. Sarmadi and K.-V. Yuen, "Structural health monitoring by a novel probabilistic machine learning method based on extreme value theory and mixture quantile modeling," Mechanical Systems and Signal Processing, vol. 173, p. 109049, 2022.

[3] C. Martín, D. Garrido, L. Llopis, B. Rubio, and M. Díaz, "Facilitating the monitoring and management of structural health in civil infrastructures with an Edge/Fog/Cloud architecture," Computer Standards & Interfaces, vol. 81, p. 103600, 2022.

[4] Y. Fujino, D. M. Siringoringo, Y. Ikeda, T. Nagayama, and T. Mizutani, "Research and implementations of structural monitoring for bridges and buildings in Japan," Engineering, vol. 5, no. 6, pp. 1093-1119, 2019.

[5] G. Song, C. Wang, and B. Wang, "Structural health monitoring (SHM) of civil structures," vol. 7, ed: MDPI, 2017, p. 789.

[6] C. Scuro, F. Lamonaca, S. Porzio, G. Milani, and R. Olivito, "Internet of Things (IoT) for masonry structural health monitoring (SHM): Overview and examples of innovative systems," Construction and Building Materials, vol. 290, p. 123092, 2021.

[7] S. Dixit and K. Sharma, "A review of studies in structural health monitoring (SHM)," in Creative Construction Conference 2019, 2019: Budapest University of Technology and Economics, pp. 84-88.

[8] R. Zinno, S. Artese, G. Clausi, F. Magarò, S. Meduri, A. Miceli, and A. Venneri, "Structural health monitoring (SHM)," The internet of things for smart urban ecosystems, pp. 225-249, 2019.

[9] A. Scianna, G. F. Gaglio, and M. La Guardia, "Structure monitoring with BIM and IoT: The case study of a bridge beam model," ISPRS International Journal of Geo-Information, vol. 11, no. 3, p. 173, 2022.

[10] M. H. Daneshvar and H. Sarmadi, "Unsupervised learning-based damage assessment of full-scale civil structures under long-term and short-term monitoring," Engineering Structures, vol. 256, p. 114059, 2022.

[11] R. Zinno, S. S. Haghshenas, G. Guido, K. Rashvand, A. Vitale, and A. Sarhadi, "The State of the Art of Artificial Intelligence Approaches and New Technologies in Structural Health Monitoring of Bridges," Applied Sciences, vol. 13, no. 1, p. 97, 2022.

[12] M. F. Bado and J. R. Casas, "A review of recent distributed optical fiber sensors applications for civil engineering structural health monitoring," Sensors, vol. 21, no. 5, p. 1818, 2021.

[13] C. Scuro, P. F. Sciammarella, F. Lamonaca, R. S. Olivito, and D. L. Carni, "IoT for structural health monitoring," IEEE Instrumentation & Measurement Magazine, vol. 21, no. 6, pp. 4-14, 2018.

[14] M. F. Bado, D. Tonelli, F. Poli, D. Zonta, and J. R. Casas, "Digital twin for civil engineering systems: an exploratory review for distributed sensing updating," Sensors, vol. 22, no. 9, p. 3168, 2022.

[15] C. A. Tokognon, B. Gao, G. Y. Tian, and Y. Yan, "Structural health monitoring framework based on Internet of Things: A survey," IEEE Internet of Things Journal, vol. 4, no. 3, pp. 619-635, 2017.

[16] H. Salehi and R. Burgueño, "Emerging artificial intelligence methods in structural engineering," Engineering structures, vol. 171, pp. 170-189, 2018.

[17] X. Ye, T. Jin, and C. Yun, "A review on deep learning-based structural health monitoring of civil infrastructures," Smart Struct Syst, vol. 24, no. 5, pp. 567-585, 2019.

[18] M. Mishra, P. B. Lourenço, and G. V. Ramana, "Structural health monitoring of civil engineering structures by using the internet of things: A review," Journal of Building Engineering, vol. 48, p. 103954, 2022.

[19] T. Wu, G. Liu, S. Fu, and F. Xing, "Recent progress of fiber-optic sensors for the structural health monitoring of civil infrastructure," Sensors, vol. 20, no. 16, p. 4517, 2020.

[20] A. Malekloo, E. Ozer, M. AlHamaydeh, and M. Girolami, "Machine learning and structural health monitoring overview with emerging technology and high-dimensional data source highlights," Structural Health Monitoring, vol. 21, no. 4, pp. 1906-1955, 2022.

[21] H. Shokravi, H. Shokravi, N. Bakhary, S. S. Rahimian Koloor, and M. Petrů, "Health monitoring of civil infrastructures by subspace system identification method: An overview," Applied Sciences, vol. 10, no. 8, p. 2786, 2020.

[22] C.-Z. Dong and F. N. Catbas, "A review of computer vision–based structural health monitoring at local and global levels," Structural Health Monitoring, vol. 20, no. 2, pp. 692-743, 2021.

[23] Y. Ren, J. Huang, Z. Hong, W. Lu, J. Yin, L. Zou, and X. Shen, "Image-based concrete crack detection in tunnels using deep fully convolutional networks," Construction and Building Materials, vol. 234, p. 117367, 2020.

[24] Y. Bao and H. Li, "Machine learning paradigm for structural health monitoring," Structural Health Monitoring, vol. 20, no. 4, pp. 1353-1372, 2021.

[25] H.-P. Chen, "Structural health monitoring of large civil engineering structures," 2018.

[26] M. Flah, I. Nunez, W. Ben Chaabene, and M. L. Nehdi, "Machine learning algorithms in civil structural health monitoring: a systematic review," Archives of computational methods in engineering, vol. 28, pp. 2621-2643, 2021.

[27] G. F. Sirca Jr and H. Adeli, "Infrared thermography for detecting defects in concrete structures," Journal of Civil Engineering and Management, vol. 24, no. 7, pp. 508-515, 2018.

[28] E. Bauer, P. M. Milhomem, and L. A. G. Aidar, "Evaluating the damage degree of cracking in facades using infrared thermography," Journal of Civil Structural Health Monitoring, vol. 8, no. 3, pp. 517-528, 2018.

[29] S. Doshvarpassand, C. Wu, and X. Wang, "An overview of corrosion defect characterization using active infrared thermography," Infrared Physics & Technology, vol. 96, pp. 366-389, 2019.

[30] P.-j. Chun and S. Hayashi, "Development of a concrete floating and delamination detection system using infrared thermography," IEEE/ASME Transactions on Mechatronics, vol. 26, no. 6, pp. 2835-2844, 2021.

[31] C. Niezrecki, J. Baqersad, and A. Sabato, "Digital image correlation techniques for non-destructive evaluation and structural health monitoring," Handbook of advanced non-destructive evaluation, p. 46, 2018.

[32] L. Ngeljaratan and M. A. Moustafa, "Structural health monitoring and seismic response assessment of bridge structures using target-tracking digital image correlation," Engineering Structures, vol. 213, p. 110551, 2020.

[33] W. W.-L. Lai, X. Derobert, and P. Annan, "A review of Ground Penetrating Radar application in civil engineering: A 30-year journey from Locating and Testing to Imaging and Diagnosis," Ndt & E International, vol. 96, pp. 58-78, 2018.

[34] I. Giannakis, F. Tosti, L. Lantini, and A. M. Alani, "Health monitoring of tree trunks using ground penetrating radar," IEEE Transactions on Geoscience and Remote Sensing, vol. 57, no. 10, pp. 8317-8326, 2019.

[35] M. Rucka, ""Non-destructive testing of structures"," vol. 13, ed: MDPI, 2020, p. 4996.

[36] S. S. Khedmatgozar Dolati, N. Caluk, A. Mehrabi, and S. S. Khedmatgozar Dolati, "Non-destructive testing applications for steel bridges," Applied Sciences, vol. 11, no. 20, p. 9757, 2021.

[37] J. Spross and T. Gasch, "Reliability-based alarm thresholds for structures analysed with the finite element method," Structural Safety, vol. 76, pp. 174-183, 2019.

[38] C. Shao, C. Gu, Z. Meng, and Y. Hu, "Integrating the finite element method with a data-driven approach for dam displacement prediction," Advances in Civil Engineering, vol. 2020, pp. 1-16, 2020.

[39] H. R. Nejati, A. Nazerigivi, M. Imani, and A. Karrech, "Monitoring of fracture propagation in brittle materials using acoustic emission techniques-A review," Comput. Concr, vol. 25, pp. 15-27, 2020.

[40] N. I. Tziavos, H. Hemida, S. Dirar, M. Papaelias, N. Metje, and C. Baniotopoulos, "Structural health monitoring of grouted connections for offshore wind turbines by means of acoustic emission: An experimental study," Renewable energy, vol. 147, pp. 130-140, 2020.

[41] Ang, M. C., Elankovan Sundararajan, K. W. Ng, Amirhossein Aghamohammadi, and T. L. Lim. "Investigation of Threading Building Blocks Framework on Real Time Visual Object Tracking Algorithm." Applied Mechanics and Materials 666 (2014): 240-244.

# Whale Optimization Algorithm for Energy-Efficient Task Allocation in the Internet of Things

Shan YANG[1]*, Renping YU[2], Xin JIN[3]

State Grid Hubei Electric Power Co. Ltd, WuHan 430077, China[1]

Hubei Huazhong Electric Power Technology Development Co., Ltd, WuHan 430077, China[2, 3]

*Abstract*—The Internet of Things (IoT) represents a new paradigm where various physical devices interact and collaborate to achieve common goals. This technology encompasses sensors, mobile phones, actuators, and other smart devices that work together to perform tasks and applications. In order to ensure optimal performance of these tasks and applications, task allocation becomes a critical aspect in IoT networks. Task allocation in IoT networks is a complex problem due to the intricate connections and interactions among devices. The task allocation issue is generally recognized as NP-hard, necessitating the development of effective optimization solutions. This paper proposes a solution using the Whale Optimization Algorithm (WOA) to address the task allocation problem in IoT networks. By leveraging the capabilities of the WOA, our algorithm aims to improve energy efficiency and enhance network stability. The performance of the algorithm was tested comprehensively on the MATLAB simulation platform. Our algorithm outperforms existing algorithms in the literature, especially in terms of energy efficiency, as per the findings.

*Keywords—Task allocation; internet of things; energy efficiency; optimization; whale optimization algorithm*

## I. INTRODUCTION

With the rise of the Internet of Things (IoT), a significant technological revolution has occurred over the past few years. The IoT envisions a network where various devices, including actuators, sensors, RFID tags, smartphones, and servers, with different capabilities can interconnect [1, 2]. The objective is to empower these network entities to collaborate efficiently and share their resources to achieve specific goals, such as executing assigned applications [3, 4]. However, the resources available in IoT networks, including electrical energy, memory, processing power, and node capabilities, are often limited. For instance, wireless sensor nodes are typically powered by batteries, resulting in constrained energy levels [5].

Similarly, RFID tags have limited processing capabilities. Considering the size of IoT networks and their heterogeneous nature, resource allocation becomes a non-trivial task to improve network performance [6]. Moreover, IoT networks exhibit dynamic behavior due to widespread deployment in smart settings like smart homes and cities [7]. These applications often rely on opportunistic sensing and networks. Opportunistic networks are characterized by the dynamic creation of connections among nodes without relying on a fixed infrastructure [8]. When forwarding a message, nodes opportunistically choose the next hop based on the probability of bringing the message closer to the recipient. Opportunistic sensing involves deploying sensors to sporadically capture data from the environment whenever their state aligns with the requirements of the application [9]. As dynamic scenarios are characterized by continuous and rapid adjustments, it is not feasible to allocate resources in a centralized manner [10]. Hence, in this context, a decentralized approach to resource allocation is necessary to deal with the dynamic nature of IoT networks [11]. Such an approach should enable nodes to autonomously manage and allocate resources based on local observations and interactions with neighboring nodes. Decentralized resource allocation methods can provide flexibility and adaptability to changing network conditions, making them suitable for IoT networks operating in dynamic and opportunistic environments [12].

IoT task allocation is a critical challenge since tasks must be assigned and fulfilled within specific deadlines. IoT environments present many challenges due to their unique properties and complexities. Task allocation belongs to the class of NP-hard problems, which makes it difficult to find optimal solutions using traditional approaches. Consequently, meta-heuristic algorithms, such as evolutionary algorithms, have emerged as effective tools for addressing this problem. Improving customer service quality is a significant concern in the IoT, and task allocation plays a crucial role in achieving this objective. Tasks represent the requirements of customers, and making appropriate decisions on how to allocate and execute these tasks can greatly enhance network performance and response quality. Various evolutionary algorithm-based strategies have been proposed to solve the task allocation problem in the IoT. These strategies aim to optimize task execution time and improve overall system efficiency compared to traditional methods.

Meta-heuristic algorithms and machine learning offer valuable solutions to address the inherent complexity of task allocation in IoT networks. Meta-heuristic algorithms, such as genetic algorithms, simulated annealing, imperialists competitive algorithm, and particle swarm optimization, provide efficient optimization strategies to tackle the NP-hard nature of task allocation problems [13, 14]. These algorithms iteratively explore the solution space, iteratively refining task assignments based on predefined objectives like energy efficiency, latency, or resource usage. Their adaptability and

ability to find near-optimal solutions make them well-suited for the dynamic and diverse IoT environment. Machine learning, on the other hand, leverages data-driven models and predictive analytics to enhance task allocation decisions. These algorithms can analyze historical task allocation patterns, device capabilities, network conditions, and application requirements to predict the most efficient task-device assignments [15, 16]. By learning and adapting from data, machine learning enables IoT systems to dynamically allocate tasks in real-time, optimizing resource utilization and response times. Furthermore, reinforcement learning approaches can allow devices to autonomously learn and improve their task allocation strategies over time based on feedback from the environment [17].

This paper proposes a novel solution using the Whale Optimization Algorithm (WOA) to address the challenging task and resource allocation problems in IoT networks. By leveraging the capabilities of the WOA, our algorithm aims to improve energy efficiency, enhance network stability, and optimize resource allocation. The performance of the algorithm is tested comprehensively on the MATLAB simulation platform, and our results demonstrate its superiority over existing algorithms in the literature, particularly in terms of energy efficiency. Our approach also involves considering two criteria, the optimal path length and the compatibility between the features of nodes and the task requirements, to determine the best nodes to execute tasks, as well as utilizing the WOA to evaluate and determine the optimal path nodes based on the defined criteria and assigning task allocation abilities to the nodes along the determined optimal path, ensuring efficient and effective task execution. In this paper, we highlight the following objectives:

- Considering two criteria, namely the optimal path length and the compatibility between the features of nodes and the task requirements, to determine the best nodes to execute tasks;

- Utilizing the WOA to evaluate and determine the optimal path nodes based on the defined criteria;

- Assigning task allocation abilities to the nodes along the determined optimal path, ensuring efficient and effective task execution.

The paper is structured as follows: Section II discusses related work in the field, Section III outlines our proposed approach in detail, Section IV presents the results of simulations conducted on the MATLAB platform, and finally, Section V summarizes the key findings and contributions.

## II. RELATED WORK

Multi-cloud computing, which combines multiple cloud providers, has emerged as a high-performance and secure platform for data processing, offering enhanced security measures against potential threats. In this context, Cai, et al. [18] developed a distributed scheduling model that integrates task scheduling and multi-cloud in IoT. The model encompasses multiple criteria, including load balancing, resource utilization, energy consumption, throughput, and cost. To address this complex scheduling problem, a multi-objective

adaptive strategy based on the sine function was proposed. The algorithm leverages the sine function's ability to capture variation tendencies in the population's diversity strategy. The outcomes from experiments prove the effectiveness of the proposed approach in achieving efficient scheduling and enhancing security measures. This work presents a novel solution for tackling the challenging task of data processing in the IoT environment.

Due to limitations in network infrastructure, efficiently transmitting the sheer volume of sensory data generated by IoT to distant data centers poses challenges in the rapidly growing era of big data. The emergence of fog computing, which uses local mini data centers near sensors, is a promising solution for real-time applications. This approach eases the main data center's burden, and cloud-based IoT is fully utilized. In this context, Boveiri, et al. [19] suggested a high-performance mechanism based on the Max-Min Ant System (MMAS), a variant of the ant colony optimization algorithm. The focus of their approach lies in the scheduling of static task graphs in homogeneous multiprocessor environments, which are commonly incorporated in fog computing systems. The key objective of the developed strategy is to effectively adjust task priority values to achieve optimal task order. By incorporating heuristic values derived from previous experience, the proposed approach demonstrates robustness and efficiency. Experimental evaluations using statistical task graphs of varying dimensions validate the effectiveness and reliability of the proposed approach compared to its traditional competitors, highlighting its performance advantages in fog computing environments.

Javanmardi, et al. [20] propose a fog task scheduler called FPFTS that combines PSO and fuzzy theory. The scheduler takes into account network utilization and application loop delay. To assess the performance of FPFTS, simulations are conducted using an IoT-based scenario in iFogSim. The experiments involve varying user movement, data rate, and response time. The findings demonstrate that FPFTS outperforms the delay-priority and first-come, first-served approaches. Specifically, FPFTS achieves an average reduction of 85.7% in delay-tolerant application loop delay compared to first-come, first-served. For delay-sensitive application loop delay, FPFTS achieves an average reduction of 87.1%. Furthermore, FPFTS achieves an average increase of 80.3% in network utilization. These findings highlight the effectiveness of FPFTS in optimizing performance metrics for fog-based IoT applications.

Bu [21] combined PSO and Genetic Algorithms for load balancing in IoT. The algorithm aims to achieve resource balance and alleviate server overload by considering various occupancy rates such as CPU, memory, and network bandwidth. These occupancy rates are used to develop the resource balance model, and a fitness function is used to estimate the influence and adjust the weights accordingly. The PSO algorithm, incorporating a disturbance factor and contraction operator, optimizes fitness functions to arrive at an optimal weight solution. The proposed hybrid algorithm is then implemented, validated, and evaluated against other approaches. The test results indicate that the proposed

algorithm outperforms other ones in terms of resource utilization, request error rate, throughput, and response time.

IoT networks frequently experience node failures due to various factors such as signal disruptions, battery drain, or hardware malfunctions. In extensive IoT networks with complex tasks, the prospect of node failures amplifies in particular regions of the network. Weikert, et al. [22] have conducted a study on node failures and proposed a new task allocation algorithm based on multi-objective optimization to address this challenge. Their algorithm, labeled as the multi-objective task allocation algorithm (MOTA), involves a specialized archive-selection mechanism to increase diversity in the search space. The reliable selection of alternative task assignments in the IoT network is facilitated by maintaining a diverse archive in case of node failures. To examine the effectiveness of their approach, they use a network simulation model and compare the findings with the baseline MOTA and the dynamic task allocation scheduler (DTAS). The performance metrics considered include network lifetime, latency, and availability. The findings of their research indicate that the suggested method leads to substantial enhancements in performance as compared to the current algorithms, especially in situations with a high ratio of tasks to nodes. This highlights the effectiveness of their approach in mitigating the impact of node failures and enhancing the overall performance of the IoT network.

Bali, et al. [23] propose a meta-heuristic algorithm called the Hybrid Artificial Bee Colony Whales Optimization (HAWO) algorithm to optimize energy consumption and time delay in task allocation for edge-based processing devices in the IoT. The HAWO algorithm is formed by combining the ABC algorithm with WOA. This integration overcomes the premature convergence issue observed in the Artificial Bee Colony algorithm, which arises from the local search in the Employee Bee phase and Onlooker Bee phase, leading to looping problems. Through simulation experiments conducted in MATLAB, the researchers observed promising results with the integrated HAWO method. Additionally, compared to benchmark works, the HAWO algorithm exhibits significant enhancements of 60% in the optimum cost metric, 50% in energy consumption, and 25% in time delay.

The rapid advancement of IoT technology has led to the development of various applications and services, including cognitive computing systems and AI-powered chatbots. Nevertheless, due to the restricted computational capacity of IoT devices, cloud services are frequently required to manage data-intensive tasks. This approach, while offloading the processing burden, results in high latency, traffic congestion, and increased energy use. To address these challenges, Fog Computing (FC) is proposed as a solution to enable faster and more efficient data processing in time-sensitive IoT applications. Nematollahi, et al. [24] present a novel architecture for offloading jobs and allocating resources in the IoT environment. This architecture consists of sensors, controllers, and Fog Computing (FC) servers as part of an

enhanced system. The later layer of the architecture operates a subtask pool approach for job offloading and employs a combination of the Opposition-based Learning (OBL) and Moth-Flame Optimization (MFO) algorithm for resource allocation, called OBLMFO. To avoid system load imbalance, a stack cache method is utilized for resource allocation in the subsequent layer.

Additionally, the architecture employs blockchain technology to ensure the precision of transaction data, enhancing resource allocation in the IoT. The evaluation of the OBLMFO model was conducted using the Python 3.9 environment, which involved a variety of different jobs. The outcomes indicate that the OBLMFO model accomplished a 12.18% drop in the delay factor and a 6.22% decline in energy usage. These findings highlight the effectiveness of the proposed architecture and OBLMFO model in enhancing the performance of resource allocation in the IoT, leading to reduced delays and improved energy efficiency.

Aghapour, et al. [25] present a method that utilizes deep reinforcement learning to address the challenges of offloading and resource allocation in the IoT. The proposed algorithm divides the problem into two sub-problems: offloading policy optimization and resource allocation optimization. The strategy for sending tasks to external devices is updated based on information obtained from the environment, and the resource allocation is optimized using the Salp Swarm Algorithm (SSA). By combining deep reinforcement learning with SSA, the proposed method aims to achieve efficient offloading and resource allocation in IoT infrastructures. The performance of the proposed algorithm is evaluated through simulations involving different deep-learning tasks executed on IoT devices with varying capacities of cloudlet devices. The results demonstrate that the proposed algorithm achieves the lowest cost in terms of energy consumption and latency. On average, it outperforms other methods, such as complete domestic processing, complete decentralization, and Jointly Resource allocation and computation Offloading PSO (JROPSO), by 92%, 17%, and 12%, respectively.

Our proposed method, based on the WOA, stands out for several reasons. In contrast to previous approaches that often struggled to optimize energy usage in IoT networks, our WOA-based method explicitly focuses on enhancing energy efficiency. Through rigorous simulations, we demonstrate that our approach significantly reduces energy consumption, making it well-suited to resource-constrained IoT devices. IoT networks are inherently dynamic and face network stability challenges. Our approach leverages the decentralized nature of the WOA to adapt dynamically to changing network conditions. This adaptability results in improved network stability, even in opportunistic and dynamic environments. Previous approaches often lacked the capability to efficiently allocate resources. Our method considers both optimal path length and compatibility between node features and task requirements, ensuring that resources are allocated to nodes best suited to execute tasks efficiently.

## III. PROPOSED APPROACH

This section introduces an algorithm aimed at addressing the task allocation problem in IoT networks. The distribution of tasks is determined by two key parameters: the ability of a particular node to perform subtasks and the distance required to execute those subtasks. The section is divided into three subsections: the problem statement, the network model, and the explanation of the proposed solution.

### A. Problem Definition

The task allocation problem is formulated using a complete graph $G = (V, E)$, where $V$ refers to the nodes representing tasks, and $E$ stands for the edges indicating the routes between the tasks. The user application is divided into multiple tasks that have specific sequential dependencies, and these dependencies are represented using a Directed Acyclic Graph (DAG). A DAG is a directed graph consisting of a collection of nodes and a collection of edges such that all the edges are in the form of $i{\rightarrow}j$, where $i$ and $j$ stand for nodes. Each node in the DAG represents a task, and an edge from node $i$ to node $j$ represents the dependency between task $i$ and task $j$. Task $j$ cannot be executed until task $i$ has been completed, and task j becomes a ready node once all its parent tasks have been completed. In the context of the DAG, node $i$ is considered a parent node of node $j$, and node $j$ is a child of node $i$. To model the costs associated with computation and communication, weights are assigned to each node and edge in the DAG. The weight assigned to a node represents the cost of computation for that task, while the weight assigned to an edge represents the cost of communication between the corresponding tasks. Fig. 1 provides an example of a DAG, illustrating the task dependencies and associated weights. This example demonstrates how the DAG representation captures the sequential relationships between tasks and the corresponding computation and communication costs.

### B. Network Model

The IoT architecture adopted in this study consists of four layers: perception, network, service management, and application, illustrated in Fig. 2. RFID tags and barcodes make up the perception layer. This layer is responsible for collecting and processing real-time information using sensors and smart devices. These devices play a crucial role in capturing data from the environment. The network layer utilizes various technologies to provide networking capabilities. It enables connectivity and communication between sensors, smart devices, and other components in the IoT ecosystem. This layer handles the high volume of data generated by sensors and smart devices, ensuring efficient data transmission and management. The service management layer focuses on analyzing information, handling security, modeling processes, and managing devices. It plays a critical role in handling the collected sensor data, analyzing it for insights, and ensuring the security and integrity of the data. Task allocation, which involves assigning tasks to appropriate resources, is also a responsibility of this layer. Finally, the application layer encompasses programs and applications classified into network type, convergence, business models, and real-time requirements. This layer provides the interface for users to interact with the IoT system and offers various services and functionalities tailored to specific application domains.



Fig. 1. A streamlined DAG for allocating IoT tasks.
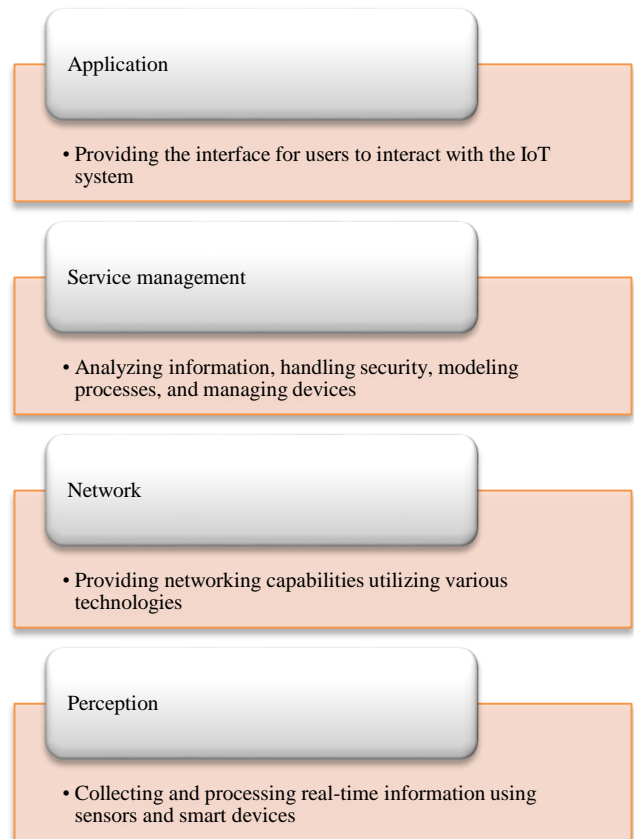


Fig. 2. IoT architecture.

## C. WOA for IoT Task Allocation

The WOA draws inspiration from the hunting behavior of humpback whales searching for food in a multidimensional space. The locations of the whales serve as decision variables, and the objective costs are represented by the distances between the whales and their food source. The algorithm consists of three main operational processes: searching, encircling, and attacking the prey. These processes determine the time-dependent location of each whale [26]. The primary presentation of the WOA is depicted in Fig. 3. Each of the operational processes is described and mathematically expressed to guide the optimization process. The search for prey involves updating the position of each whale based on its current position and velocity. The encircling method simulates the collaboration between whales to encircle the prey and optimize the search process. The shrinking encircling prey process further refines the search space by adjusting the positions and velocities of the whales.
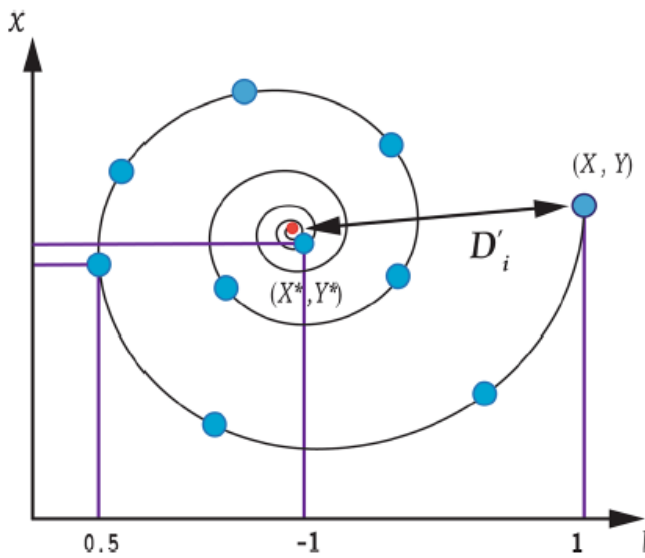


Fig. 3. Position update in a spiral.

The encircling behavior of whales during optimization is mathematically modeled using Eq. (1) and Eq. (2). These equations describe how whales update their positions to imitate the encircling behavior found around the best search agent at the moment.

$$\vec{D} = \left| \vec{C}.\overrightarrow{X^*}(t) - \vec{X}(t) \right| \quad (1)$$

$$\vec{X}(G+1) = \overrightarrow{X^*}(t) - \vec{A}.\vec{D} \quad (2)$$

*X* stands for the position vector, *C* and *A* refers to the coefficient vectors, and *t* is the current iteration. *X\** denotes the position vector of the most optimal solution found thus far. *X\** will be updated if there is a better solution for each iteration. Eq. (3) and Eq. (4) are used to calculate the coefficient vectors *A* and *C*.

$$\vec{A} = 2\vec{a}.\vec{r} - \vec{a} \quad (3)$$

$$\vec{C} = 2\vec{a} \quad (4)$$

Eq. (3) and Eq. (4) contain a coefficient vector $a$ that gradually diminishes from 2 to 0 during the iterations and an unpredictable vector $r$ that change from 0 to 1.

The bubble net attacking strategy serves as the basis for modeling the attacking behavior. To simulate the bubble-net behavior of humpback whales, two main approaches are employed. These approaches are the shrinking encircling mechanism and the spiral updating position mechanism, as depicted in Fig. 3. Humpback whales can utilize either of these mechanisms to capture their prey, with each mechanism occurring randomly with a 50% probability. To introduce randomness, a variable "p" is introduced that ranges between 0 and 1. In the shrinking encircling mechanism, the value of "a" in Eq. (3) is progressively decreased. The value of "A" is determined randomly within the range of [-a, a], while "a" itself decreases gradually from two to zero over a specified number of iterations.

On the other hand, the spiral updating position mechanism mimics the helix-like maneuvering pattern of humpback whales. During the prey attack phase, the optimization algorithm focuses on exploiting potential solutions. Exploitation involves searching within a restricted yet promising region of the search space, with the aim of improving the quality of solutions in the vicinity of a solution denoted as 'S'. This operation intensifies and refines the search around 'S'. The value of "A" ranges between -1 and 1. When |A| is less than 1, exploitation is induced, and all search agents converge to obtain the best possible solution. The updating model can be described using Eq. (5).

$$\vec{X}(t+1) = \begin{cases} \overrightarrow{X^*}(t) - \vec{A}.\vec{D} & if \; p < 0.5 \\ \overrightarrow{D'}.e^{bl}.\cos(2\pi l) + \overrightarrow{X^*}(t) & if \; p \geq 0.5 \end{cases} \quad (5)$$

During the exploration phase, the focus shifts towards exploring new areas of the search space in order to discover potentially better solutions resembling a global search. This phase relies on the variation of the vector "A" to mobilize the search agents. By setting the absolute value of "A" greater than 1, the search agent is forced to diverge significantly in the search space. This stands in stark contrast to the exploitation phase. In the exploration phase, the search agents update their positions by referencing a randomly selected search agent rather than the best search agent, as in the exploitation phase. This introduces a stochastic element into the search process, enabling the exploration of different regions. The searching mechanism can be mathematically represented by Eq. (6) and Eq. (7).

$$\vec{D} = \left| \vec{C}.\overrightarrow{X_{rand}} - \vec{X} \right| \quad (6)$$

$$\vec{X}(t+1) = \overrightarrow{X_{rand}} - \vec{A}.\vec{D} \quad (7)$$
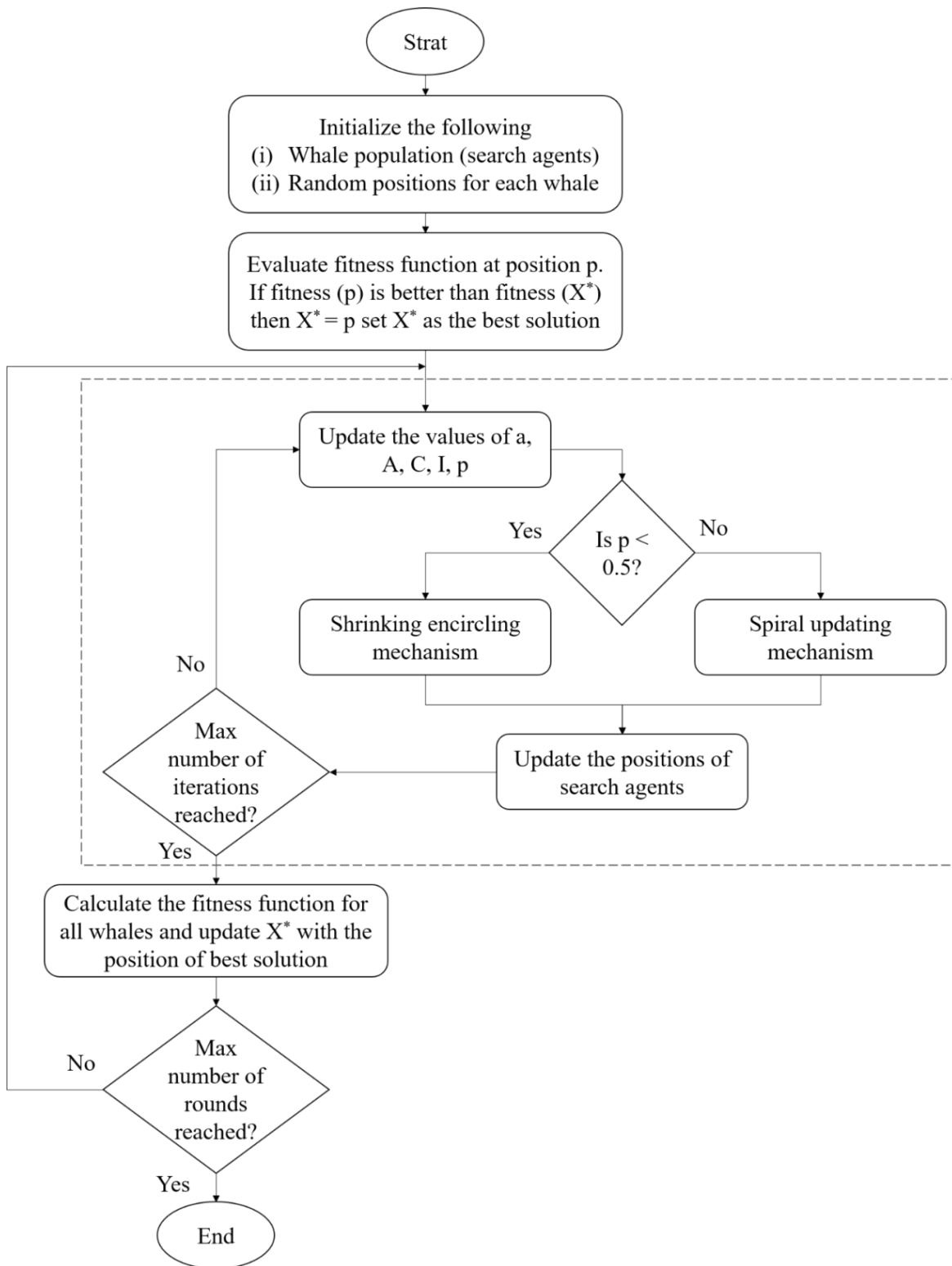
Fig. 4. Flowchart of the proposed algorithm.

The IoT task allocation problem is addressed using the WOA, where the solution is mapped to the positions of whales. The allocation results are represented by a matrix $x = [x_{ij}]$, where $i$ and $j$ represent the indices of tasks and resources, respectively. If task $T_i$ is allocated to resource $R_j$, then $x_{ij} = 1$.

Conversely, if $x_{ij} = 0$, it indicates that the corresponding whale group's position can be used for task allocation. The WOA simulates the movement and feeding behaviors of whales to find the optimal positions for whale groups, which correspond to the optimal allocation of IoT tasks. The flowchart of the

proposed algorithm is shown in Fig. 4. The process of IoT task allocation using the WOA typically involves the following steps:

- Initialization: Initialize the whale population and set the parameters for the optimization process, such as the maximum number of iterations and the convergence threshold.

- Fitness evaluation: Evaluate the fitness of each whale group based on the task allocation solution represented by the matrix x. The fitness function considers various factors, such as energy efficiency, stability, and resource utilization.

- Updating the best solution: Keep track of the best task allocation solution found so far, and update it whenever a better solution is discovered during the optimization process.

- Movement and feeding: Apply the movement and feeding behaviors of whales to update the positions of the whale groups. This step involves exploring the search space to find better task allocation solutions.

- Exploration and exploitation: Balance the exploration and exploitation of the search space by adjusting the parameters of the WOA, such as the search range and the degree of randomness in the movement and feeding behaviors.

- Convergence check: Check if the optimization process has converged, either by reaching the maximum number of iterations or by achieving a satisfactory level of task allocation performance.

- Termination: End the optimization process and output the best task allocation solution obtained.

## IV. RESULTS AND DISCUSSION

In this section, a comparative analysis of the proposed task allocation method is presented, taking into account the application DAG and connection costs, as depicted in Fig. 1. MATLAB is selected as the programming platform for its capability in matrix calculations, practical functions, and seamless data exchange with different programming languages. It offers high-level programming capabilities and is widely used for computational methods and mathematical problem-solving in academia. For the simulation of the proposed method, MATLAB R2022 is utilized. The dataset from [27] serves as the foundation for this study. Task allocation policies in the IoT have a direct impact on application performance and efficient resource utilization. Finding the optimal approach for task assignment in the IoT presents a significant challenge. The procedure for task assignment in the IoT environment is as follows: initially, tasks and resources are mapped based on the available task and resource data. This mapping ensures task completion and QoS by assigning appropriate resources to tasks. Finally, the submitting user receives an overview of the results, providing an overall understanding of the task allocation outcomes. The convergence diagram for the proposed method is illustrated in Fig. 5. The results indicate that approximately 350 generations of the proposed algorithm

were required to achieve the correct answer, showcasing the effectiveness and convergence of the proposed approach.
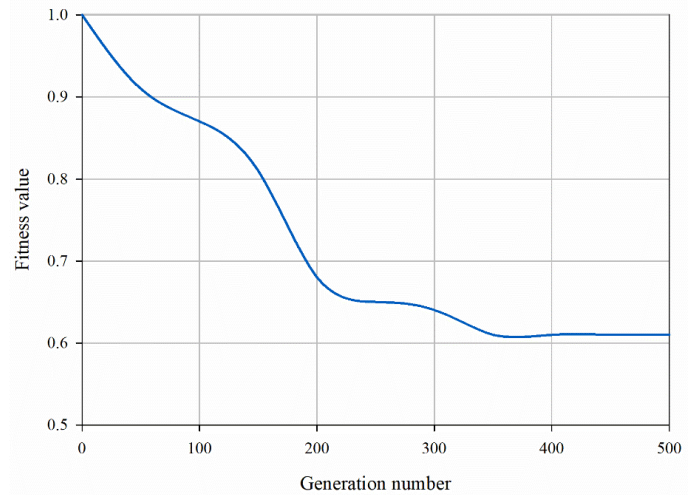


Fig. 5. Convergence diagram.
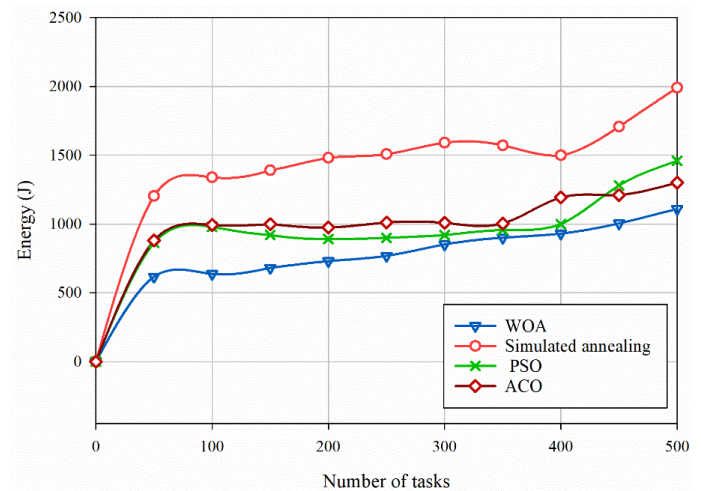


Fig. 6. Energy consumption comparison.

Task allocation in the IoT plays a significant role in energy consumption. In IoT architectures, data centers have the potential to optimize their energy usage by employing strategies such as migrating low-load or idle servers to other servers, shutting down underutilized servers, and transferring idle workloads to different servers. Fig. 6 presents the energy consumption of various algorithms for different task counts. The results demonstrate that as the number of tasks increases, the suggested algorithm exhibits superior energy efficiency compared to other algorithms. This indicates that the proposed algorithm effectively manages energy consumption, making it a favorable choice for IoT task allocation. The IoT offers a favorable environment for users, providing access to software and hardware resources at a reduced cost. In such a network, effective allocation of resources is crucial, benefiting both IoT service providers and ensuring prompt response to user requirements. One of the most critical challenges in the IoT is cost-effective resource allocation. Therefore, it is vital to employ efficient algorithms to address this issue. Fig. 7 illustrates the cost diagram of the proposed method in

comparison to other algorithms, highlighting its effectiveness in reducing the overall cost. The diagram illustrates the superior capability of the proposed method in minimizing costs when compared to alternative approaches. This emphasizes the algorithm's power in optimizing resource allocation and achieving cost efficiency in the IoT environment.
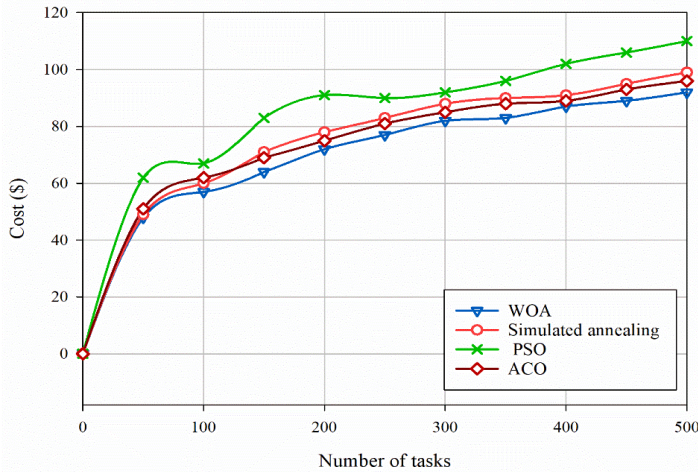


Fig. 7. Cost comparison.

## V. CONCLUSION

With the rapid advancement of IoT technology, the convergence of multiple networks has become the prevailing trend in the IoT landscape. This paper addresses the challenge of optimizing network resource allocation in multiple heterogeneous IoT networks to facilitate seamless information exchange across different services. To achieve this, the proposed approach utilizes a resource allocation algorithm based on the WOA. The primary objectives of this algorithm are to enhance energy efficiency and minimize network latency within IoT networks. Compared to other optimization algorithms such as ACO, simulated annealing, and PSO, our proposed solution demonstrates superiority in selecting optimal assignment decision policies for task allocation and scheduling. Optimizing local and global processes, our approach promises energy efficiency and low-latency communication in the heterogeneous IoT environment. We plan to explore task capability similarity to predict task execution paths in our future work, which could lead to better outcomes. Furthermore, we aim to compare task capabilities to effectively coordinate them, leading to improved outcomes in IoT resource allocation.

## REFERENCES

[1] B. Pourghebleh and N. J. Navimipour, "Data aggregation mechanisms in the Internet of things: A systematic review of the literature and recommendations for future research," Journal of Network and Computer Applications, vol. 97, pp. 23-34, 2017.

[2] P. He, N. Almasifar, A. Mehbodniya, D. Javaheri, and J. L. Webber, "Towards green smart cities using Internet of Things and optimization algorithms: A systematic and bibliometric review," Sustainable Computing: Informatics and Systems, vol. 36, p. 100822, 2022, doi: https://doi.org/10.1016/j.suscom.2022.100822.

[3] F. Kamalov, B. Pourghebleh, M. Gheisari, Y. Liu, and S. Moussa, "Internet of Medical Things Privacy and Security: Challenges, Solutions, and Future Trends from a New Perspective," Sustainability, vol. 15, no. 4, p. 3317, 2023.

[4] R. Singh et al., "Analysis of Network Slicing for Management of 5G Networks Using Machine Learning Techniques," Wireless Communications and Mobile Computing, vol. 2022, 2022.

[5] B. Pourghebleh and V. Hayyolalam, "A comprehensive and systematic review of the load balancing mechanisms in the Internet of Things," Cluster Computing, pp. 1-21, 2019.

[6] B. Pourghebleh, V. Hayyolalam, and A. A. Anvigh, "Service discovery in the Internet of Things: review of current trends and research challenges," Wireless Networks, vol. 26, no. 7, pp. 5371-5391, 2020.

[7] M. K. Hasan et al., "A review on security threats, vulnerabilities, and counter measures of 5G enabled Internet‐of‐Medical‐Things," IET Communications, vol. 16, no. 5, pp. 421-432, 2022.

[8] T. Samizadeh Nikoui, A. M. Rahmani, A. Balador, and H. Haj Seyyed Javadi, "Internet of Things architecture challenges: A systematic review," International Journal of Communication Systems, vol. 34, no. 4, p. e4678, 2021.

[9] M. Mohseni, F. Amirghafouri, and B. Pourghebleh, "CEDAR: A cluster-based energy-aware data aggregation routing protocol in the internet of things using capuchin search algorithm and fuzzy logic," Peer-to-Peer Networking and Applications, pp. 1-21, 2022.

[10] A. Peivandizadeh and B. Molavi, "Compatible authentication and key agreement protocol for low power and lossy network in IoT environment," Available at SSRN 4194715, 2022.

[11] J. Jiao, Y. Sun, S. Wu, Y. Wang, and Q. Zhang, "Network utility maximization resource allocation for NOMA in satellite-based Internet of Things," IEEE Internet of Things Journal, vol. 7, no. 4, pp. 3230-3242, 2020.

[12] S. Habib, S. Aghakhani, M. G. Nejati, M. Azimian, Y. Jia, and E. M. Ahmed, "Energy management of an intelligent parking lot equipped with hydrogen storage systems and renewable energy sources using the stochastic p-robust optimization approach," Energy, p. 127844, 2023.

[13] S. Mahmoudinazlou, A. Alizadeh, J. Noble, and S. Eslamdoust, "An improved hybrid ICA-SA metaheuristic for order acceptance and scheduling with time windows and sequence-dependent setup times," Neural Computing and Applications, pp. 1-19, 2023.

[14] V. Hayyolalam, B. Pourghebleh, M. R. Chehrehzad, and A. A. Pourhaji Kazem, "Single‐objective service composition methods in cloud manufacturing systems: Recent techniques, classification, and future trends," Concurrency and Computation: Practice and Experience, vol. 34, no. 5, p. e6698, 2022.

[15] T. Gera, J. Singh, A. Mehbodniya, J. L. Webber, M. Shabaz, and D. Thakur, "Dominant feature selection and machine learning-based hybrid approach to analyze android ransomware," Security and Communication Networks, vol. 2021, pp. 1-22, 2021.

[16] S. N. H. Bukhari, J. Webber, and A. Mehbodniya, "Decision tree based ensemble machine learning model for the prediction of Zika virus T-cell epitopes as potential vaccine candidates," Scientific Reports, vol. 12, no. 1, p. 7810, 2022.

[17] B. M. Jafari, M. Zhao, and A. Jafari, "Rumi: An Intelligent Agent Enhancing Learning Management Systems Using Machine Learning Techniques," Journal of Software Engineering and Applications, vol. 15, no. 9, pp. 325-343, 2022.

[18] X. Cai, S. Geng, D. Wu, J. Cai, and J. Chen, "A multicloud-model-based many-objective intelligent algorithm for efficient task scheduling in internet of things," IEEE Internet of Things Journal, vol. 8, no. 12, pp. 9645-9653, 2020.

[19] H. R. Boveiri, R. Khayami, M. Elhoseny, and M. Gunasekaran, "An efficient Swarm-Intelligence approach for task scheduling in cloud-based internet of things applications," Journal of Ambient Intelligence and Humanized Computing, vol. 10, no. 9, pp. 3469-3479, 2019.

[20] S. Javanmardi, M. Shojafar, V. Persico, and A. Pescapè, "FPFTS: A joint fuzzy particle swarm optimization mobility‐aware approach to fog task scheduling algorithm for Internet of Things devices," Software: Practice and Experience, 2020.

[21] B. Bu, "Multi-task equilibrium scheduling of Internet of Things: A rough set genetic algorithm," Computer Communications, vol. 184, pp. 42-55, 2022.

[22] D. Weikert, C. Steup, and S. Mostaghim, "Availability-Aware Multiobjective Task Allocation Algorithm for Internet of Things

Networks," IEEE Internet of Things Journal, vol. 9, no. 15, pp. 12945-12953, 2022.

[23] M. S. Bali et al., "An efficient task allocation framework for scheduled data in edge based Internet of Things using hybrid optimization algorithm approach," Physical Communication, vol. 58, p. 102047, 2023.

[24] M. Nematollahi, A. Ghaffari, and A. Mirzaei, "Task and resource allocation in the internet of things based on an improved version of the moth-flame optimization algorithm," Cluster Computing, pp. 1-23, 2023.

[25] Z. Aghapour, S. Sharifian, and H. Taheri, "Task offloading and resource allocation algorithm based on deep reinforcement learning for distributed AI execution tasks in IoT edge computing environments," Computer Networks, vol. 223, p. 109577, 2023.

[26] S. Mirjalili and A. Lewis, "The whale optimization algorithm," Advances in engineering software, vol. 95, pp. 51-67, 2016.

[27] D. M. Abdelkader and F. Omara, "Dynamic task scheduling algorithm with load balancing for heterogeneous computing system," Egyptian Informatics Journal, vol. 13, no. 2, pp. 135-145, 2012.

# An Optimized Deep Learning Method for Video Summarization Based on the User Object of Interest

Hafiz Burhan Ul Haq, Watcharapan Suwansantisuk, Kosin Chamnongthai

Faculty of Engineering-Department of Electronics and Telecommunication Engineering,
King Mongkut's University of Technology Thonburi (KMUTT), Bangkok, 10140, Thailand

*Abstract*—Surveillance video is now able to play a vital role in maintaining security and protection thanks to the advancement of digital video technology. Businesses, both private and public, employ surveillance systems to monitor and track their daily operations. As a result, video generates a significant volume of data that needs to be further processed to satisfy security protocol requirements. Analyzing video requires a lot of effort and time, as well as quick equipment. The concept of a video summary was developed in order to overcome these limitations. To work past these limitations, the concept of video summarization has emerged. In this study, a deep learning-based method for customized video summarization is presented. This research enables users to produce a video summary in accordance with the User Object of Interest (UOoI), such as a car, airplane, person, bicycle, automobile, etc. Several experiments have been conducted on the two datasets, SumMe and self-created, to assess the efficiency of the proposed method. On SumMe and the self-created dataset, the overall accuracy is 98.7% and 97.5%, respectively, with a summarization rate of 93.5% and 67.3%. Furthermore, a comparison study is done to demonstrate that our proposed method is superior to other existing methods in terms of video summarization accuracy and robustness. Additionally, a graphic user interface is created to assist the user with summarizing the video using the UOoI.

*Keywords—Video summarization; deep learning; user object of interest; surveillance systems; SumMe*

## I. INTRODUCTION

Globally, everyone's first priority is security. On both private and public assets, video surveillance cameras have been deployed as well as other security measures to address this difficulty. At homes, businesses, airports, banks, and other public locations, a variety of security surveillance cameras—both stationary and mobile—have been placed. These cameras are extremely important for monitoring and spotting anomalous activities. They are also useful for assisting with the investigation of incidents or crime scenes, such as car accidents, robberies, murders, and terrorist activities. Additionally, there are presently expected to be over 770 million cameras in use worldwide [1]. Over 2,500 petabytes of video data are produced each day by these cameras, which are typically always in use [2]. It is also estimated that projection growth will exceed 120 zettabytes in 2023 [3]. Every minute, 500 hours of videos are posted to YouTube [4]. Fig. 1 displays daily statistics on the actual data generated by the video surveillance cameras around the world.

Motion detection, time monitoring, facial recognition, recognition of license plates, and other content-based video analysis technologies have already made great progress in the development of video analytic technology. The issue is that manual analysis of the video recordings still needs human intervention (camera operator, security personnel, etc.). Because visual inspection requires concentration and watching the entire video, it is challenging and time-consuming to extract useful information from video footage. In the event of lengthy videos, it could potentially lead to false negatives. Therefore, it is imperative to find a solution that reduces the human time and effort required for manual analysis. To solve this issue, attempts are being made to create a video summary that quickly conveys the essence of the entire video [5]. By identifying and presenting the most interesting and up-to-date content to potential consumers, video summarizing (VS) creates a summary of substantial video content. Security surveillance systems use video surveillance to detect and analyze suspicious or anomalous activity. Individuals also use VS to share sporadic videos on social media, create highlights of different sports, create movie and television trailers, index video content to enable quick browsing of large amounts of video through video search engines, etc. [6, 7]. There have been various attempts by the researchers to propose an automated VS. The majority of VS approaches provide a summary based on choosing key frames that best depict the video during the skimming procedure. For video summarization, the shot boundary detection techniques [8–15] are widely known. Instead of concentrating on a single item, feature-based techniques [16–34] for VS provide a generalized video summary. These methods have trouble accurately recognizing the item, which prevents them from meeting the user's needs. The video is distilled using trajectory-based [6, 25] and clustering [17, 22, 35–38] algorithms that highlight related objects, actions, and events. These methods, however, do not produce a summary of any video that provides information based on the user's interests. As a result, these methods restrict the usage of retrieval tasks and do little to improve users' observing experiences. The summarizing of a video may be accomplished during the video skimming process by choosing shot portions with the use of video editing software like Filmora [38], SpenShot [39], and Davinci [40].

The aforementioned tools are expensive, need extensive storage, and require user skill. In order to capture the user's attention, it is also important to carefully choose segments that accurately portray the complete video. However, the key-frame extraction process appears appropriate for bandwidth-constrained devices and gives the video's core subject in a few frames. Similarly most of the existing techniques work on the principle of key-frame selection by eliminating the redundant

frames that may result in loss of important information related to a user's interest and create vagueness. Many surveillance cameras have been erected in public locations to monitor suspicious actions such as mobile phone snatching, terrorism, robbery, and so on, where the information contained in every single frame is critical. As a result, these strategies restrict the usage of retrieval tasks and do not contribute to improving the users' observing experience. Due to the limitation (disappearance of object and event), these techniques are unable to produce significant results. Though there are various ways that summarize the video based on the user's interest, their fundamental issue is their high processing power needs and limited accuracy.
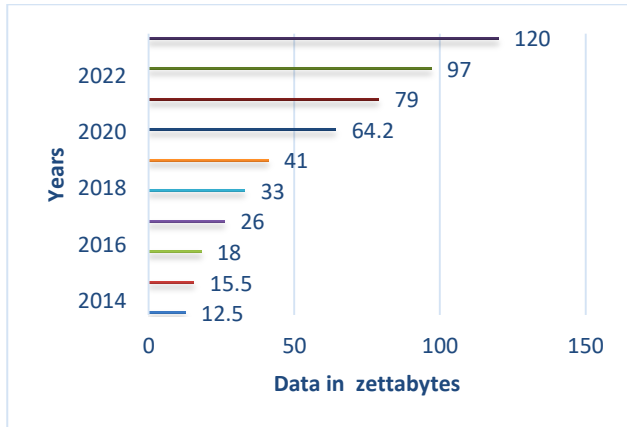


Fig. 1.    Yearly production of the video's data [3].

This paper proposes a powerful VS method built on the User Object of Interest (UOoI) to address the challenges of video summarizing. The UOoI is the object that a user selects to collect all of the frames in which the selected object appears to summarize the movie. Examples of such objects are people, purses, mobile phones, motorcycles, etc. The proposed VS method has three main steps: i) the selection of the UOoI phase; ii) the detection of the object phase; and iii) the summarization of the video based on the UOoI phase. In order to exclude the unneeded noisy items (other than the OoI) that are essential for the object segmentation, the UOoI selection is first carried out from a database. Then, in order to detect an object that is thought to be a UOoI, the detector YOLOv3 is used. The VS algorithm detects the objects and then summarizes the video, relying on the UOoI. The implications of the proposed method may be summed up as follows, based on the discussion above:

- Initially selection of UOoI is done. The proposed technique chooses the object from the repository and automatically throws out any unnecessary objects; the YOLOv3 is then utilized to discover the needed object.

- The VS technique may identify a single object as well as several objects in a video clip.

- The proposed technique effectively summarizes the video and outperforms all difficulties demonstrated in the SumMe [40] and self-created Dataset.

- The experiments analysis demonstrates that the proposed method works better than cutting-edge techniques in the field of VS.

The remainder of the article is structured as follows: The literature review for departing strategies is described in Section II. The proposed VS method that describes the video summarizing technique is presented in Section III. Section IV discussed the experimental analysis and results. However, the comparative analysis is performed in Section V. Section VI provides an overview of the graphical user interface. Finally, Section VII addresses the conclusion and future work.

## II.    LITERATURE REVIEW

Several VS approaches have been put forth in the literature. A technique for summarizing the video developed by Ngo et al. [33] is based on content balance and perceptual quality. The task was completed by immediately identifying moving objects, which were then used to apply video optimization. An event-based video clarification approach has been presented by Damnjanovic et al. [19]. The method first totals the absolute difference in pixel values between the current frame and the reference frame before calculating each frame's energy. All of the current events in the frames are identified in this manner. The technique for video summarization is then used to extract keyframes. Using three processes to produce the video summary: extracting visual elements, summarizing the movie, and filtering it.

A two-stage technique is presented by Miniakhmetova and Zymbler [10] to produce a personalized summary of the video. The first step is video structure, which involves using different scene identification algorithms to produce a video summary. Using the detection bank, items are picked out of the frames of videos in the second step. The most influential sequences in which items are recognized, which later form a region of the user's interest, are included in the video summary that is produced. Three primary steps—shot boundary identification, redundant frame reduction, and stroboscopic imaging—can be used to summarize video according to a method suggested by Varghese and Nair [8].

The neighboring frame is compared to the current frame to determine the shot boundary. After that, the Structural Similarity Index (SSI) is adopted to eliminate repeating frames. The strobe is also used to display the activities that are already taking place in the film and to grasp the common backdrop. In comparison to the original video, the summarized video's overall volume has decreased by 55%. Lai et al. [15] developed a frame re-composition-based technique utilizing a clustering algorithm, optical flow, and background reduction with the goal of recognizing foreground elements. The foreground object has been identified thanks to the fusion of several pixels. Once the objects or actions have been seen, a sliding window has been utilized to integrate the recognized elements in succeeding frames to produce a spatiotemporal trajectory. The full spatiotemporal trajectory is combined to produce the video summary, and the algorithm has a 97% accuracy rate.

Three factors may be employed to determine a video's summary, according to Srinivas et al. [17]. First, each frame is given a score based on a variety of factors, such as color,

statistical attention, quality, demonstration, temporal segment, and uniformity. After that, it assigns a weight to each value based on the position of the attribute for producing key frames. The weighting is determined using the standard deviation. Lastly, the repeated frames are removed, with frames being gathered in ascending order by considering score. In comparison to previous strategies, this keyframe selection method yields outcomes that are 1.8% better. Frame selection in lecture clips has been studied by Davila and Zanibbi [32], who focused on segmentation by reducing content section conflicts, deleting objects, and re-building every frame to produce a summary of the video. The Kalman filter has been used to monitor human movements in Ajmal et al.'s [27] approach to determining the trajectory. The properties of color are useful for video since the color histogram may be utilized to identify shots and provide a synopsis of the video.

To identify an aberrant frame and eliminate noisy information from the video, Ma et al. [9] have developed a shared representation of neighboring frames. Keyframes are chosen using minimal sparse reconstruction to minimize noise and preserve critical information. A keyframe is the frame with a significant aberrant representation inaccuracy. The average percentage of reconstruction (APOR) and the sparse border are used to manage the keyframe count in a greedy iterative technique for model optimization. A cloud-based system called HOMER was introduced by Meyer et al. [41] for the creation of video highlights. With this technology, the user's emotions may be detected in order to provide a video summary. A dataset captured using a dual-camera system and a video of a home randomly chosen from Microsoft's Video Titles in the Wild (VTW) dataset are both used for experimental research. As a result, HOMER improved by 38% above baseline. Uncertainty detection and image processing technique in decision making has been presented [42-43]. ResNet 152 and a Gated Recurrent Unit (GRU) were used in tandem to summarize a movie, according to Afzal and Tahir [44]. The deep features that were present in the movie are extracted using ResNet 152 in this technique. Similarly, a GRU is utilized to increase the approach's performance and resilience. Utilizing the F-measure 43.7 and the SumMe dataset, an experimental study is conducted. A brief overview of current VS approaches is discussed in Table I.

The majority of current solutions remove unnecessary frames and a few key frames that can lose crucial information pertaining to a user's interest. In order to monitor suspicious actions like mobile theft, terrorism, robberies, etc., where the information contained in each single frame is crucial, numerous surveillance cameras have been erected in public spaces. These methods are unable to yield meaningful results because of the restriction (the disappearance of objects and events). Additionally, no method produces a summary of a video according to the user's specifications, such as one based on a single item (person, car, etc.). The proposed VS method is straightforward and incredibly reliable; it quickly and accurately generates a summary of a video depending on the user's requirements. The user chooses the UOoI as an input in the proposed method, and the algorithm generates the output in accordance with the user's requirements.

TABLE I.     BRIEF OVERVIEW OF EXISTING VS METHODS

| Sr. No. | Authors | Methodology | Remarks |
|---|---|---|---|
| 1 | Varghese and Nair [8] | For the purpose of inspecting the common backdrop frames, stroboscopic effect is used. | 55% reduces of video duration. |
| 2. | Lai *et al.* [15] | By using frame re-composition, it is deleting the irrelevant spatio-temporal segments. For the purpose of creating a video summary, the extracted items are reconnected in the spatiotemporal trajectory. | Only a stationary camera is capable of detecting objects. |
| 3. | Ma *et al.* [9] | To optimize the model based on the adjacent frame, utilize the iteration method that use the average percentage of frame reconstruction. | Dedicated only to fixed-size frames. |
| 4 | Davila and Zanibbi [32] | Focusing the lecture video on the hand-written material that was present on the whiteboard and summarizing the film by removing any uncertainty between the topic sections. | Lower in term of accuracy. |
| 5 | Damnjanovic *et al.* [19] | Identifying and grouping the events shown in CCTV footage. Additionally, two summary types static and dynamic were added. | The main drawback is the possibility of falsely detecting events when the backdrop environment changes. |
| 6 | Ngo *et al.* [33] | This method of video summary caught both attention values and the structure of the video. Video can be organized in a hierarchical tree depending on scenes, groups, etc. to eliminate redundancy. | Low summarization rate about 10-15% |
| 7 | Miniakhmetova and Zymbler [10] | Make a description of the video based on user comments that include likes, dislikes, and neutral criticism in light of aspects influencing the scenario, including item appearance. | Prototype is missing. |
| 8 | Ajmal *et al.* [27] | The Support Vector Machine (SVM) classifier may be used to recognise the individual using a Histogram of Oriented Gradient (HOG), and the Kalman filter can be used to monitor mobility. | By making browsing quickly, the technology decreases video storage and saves time. |

## III. PROPOSED METHODOLOGY

Fig. 2 depicts the architecture of the proposed VS system based on the UOoI. The following key modules make up the suggested system:

- UOoI detection module: detect UOoI in videos using deep learning.

- Dictionary: The UOoI's data repository.

- The video summary is produced by the video summarization module using the frames having a UOoI in the video.
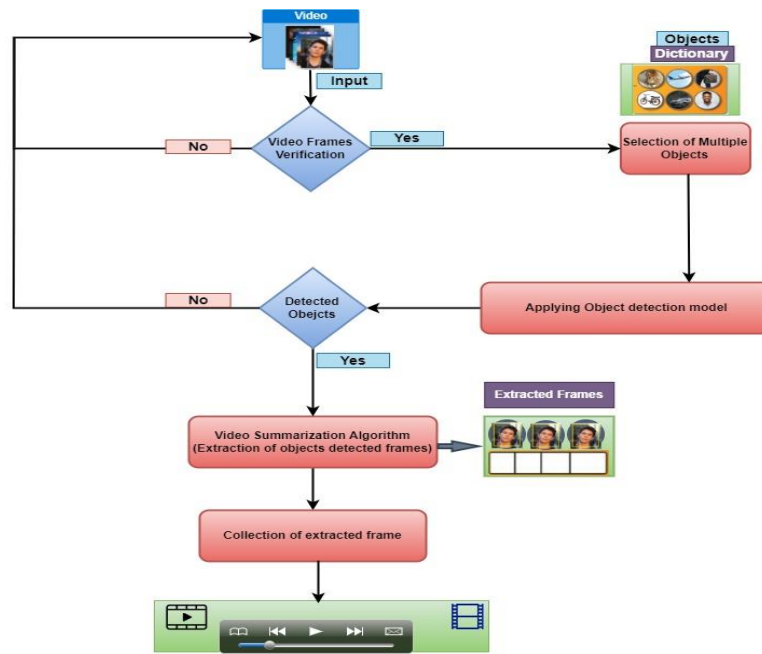
Fig. 2.    Proposed method flow diagram.

### A. *User Object of Interest (Repository)*

Defining the UOoI is the initial stage for VS. An 80-item UOoI dictionary is made specifically for this purpose. The COCO dataset, which comprises 330 thousand pictures and more than 200 thousand labeled images, is used to define the UOoI. It also offers 80 categories for things like cars, people, and handbags [45].

### B. *Object Type Detection*

Yolo (You Look Only Once) v3 is employed in the intended attempt to identify the OoI. The position of the scene and picture where the UOoI is detected and categorized according to the category, such as a person, automobile, bicycle, etc., is determined by the object's detection. Yolo v3 employs a 53-layer modified darknet that is trained on Imagenet. In addition, 53 more layers have been added for job identification, giving Yolo v3's underlying architecture a total of 106 layers. To avoid losing low-level data, there is no pooling layer, and the feature maps are down-sampled using a convolutional layer with stride 2. YOLOv3 is substantially quicker at identifying objects than other object recognition methods [46]. The entire video is processed by Yolo v3 using just one neural network. The network divides the images into areas and generates bounding boxes and probabilities for each region. Logistic regression is used in YOLO v3 to forecast each class score, and a threshold may be used to predict an object's multiple labels. The courses that have scores over a certain level, however, are put in the box [47]. Fig. 3 describes the prediction of bounding box.

where, the bounding-box's x and y dimensions are ($b_x$,$b_y$). However, four coordinates predicted by YOLO v3 such $t_x$, $t_y$, $t_w$, $t_h$ for each bounding box. The predictions are shown as follows if the cell is offset by ($C_x$,$C_y$) from the image's top-left corner and the bounding box prior has dimensions of $p_w$,$p_h$:
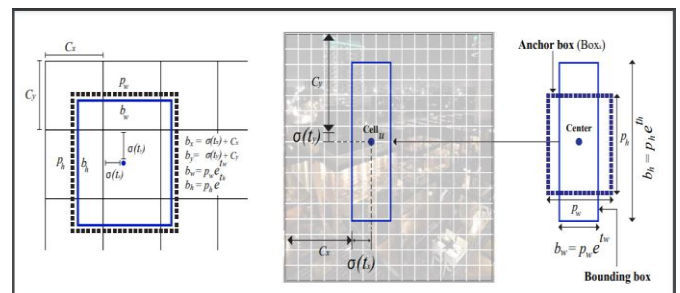


Fig. 3.    Prediction of the bounding box.

$$b_x = \sigma(t_x) + c_x \tag{1}$$

$$b_y = \sigma(t_y) + c_y \tag{2}$$

$$b_w = p_w \, e^{t_w} \tag{3}$$

$$b_h = p_h \, e^{t_h} \tag{4}$$

$$Cofindence = \Pr(Obj).IOU_{Prediction}^{truth} \tag{5}$$

$$IOU = \frac{area(box_{prediction} \cap (box_{truth})}{area(box_{prediction} \cup (box_{truth})} \tag{6}$$

However, Pr(obj) is the value of the probability that an object existed in the grid. The value of Pr(obj) as well as confidence are dependent on object existence in grid. For example, the score of Pr(obj) is 1 if the object is in a grid. Similarly, the score is 0 if the confidence is 0. Eq. (6) describes the $IOU_{prediction}^{truth}$ which is the ratio between predicted objects and real objects. ($box_{prediction} \cap (box_{truth})$) describes the area of the intersection between predicted and real objects; whereas $area(box_{prediction} \cup (box_{truth})$ describe the area that is combined regarding predicted and real objects. Similarly, the object class is predicted $Pr(cls|Obj)$ and defined when it appears in the grid. In such a case, the confidence is measured by the multiplication of the predicted class by the probability of

an object with box convergence, as mentioned in the following equations:

$$Confidence(M) = \Pr(cls|Obj).\Pr(Obj).IOU_{Prediction}^{truth} \quad (7)$$

$$= \Pr(cls_M).IOU_{Prediction}^{truth} \quad (8)$$

### C. Comparison in Terms of Speed and Accuracy

In terms of speed, when compared to other models, Yolo v3 is the best object detection model. YOLO v3 processes data at a rate of 45 fps, which is rather fast in contrast to single-shot detectors (SSD), Faster-RCNN, and R-FCN. YOLO v3's speed performance against other object identification models is shown in Fig. 4. Accuracy, taken into account for the comparison, is another crucial element, as mentioned in Fig. 5. The model Faster-RCNN executes with an accuracy rate greater than YOLO v3, but YOLO v3 has significantly better accuracy than most of the other models. It operates in a realistic situation considerably more slowly than Yolo v3 does. Many other algorithms, like the R-CNN family and SSDs, operate similarly but take longer to complete because of their numerous, intricate phases. On the other hand, YOLO v3 uses single-stage detection to complete the same task using a single neural network. When compared to other models, YOLO v3 operates precisely and executes more quickly, for example, detecting 45 frames per second as opposed to the Faster-RCNN family's detecting just five frames per second [48–49].
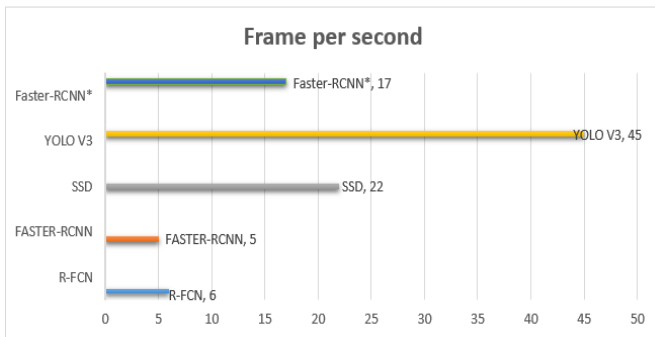


Fig. 4. Comparison of object detection models in term of speed.
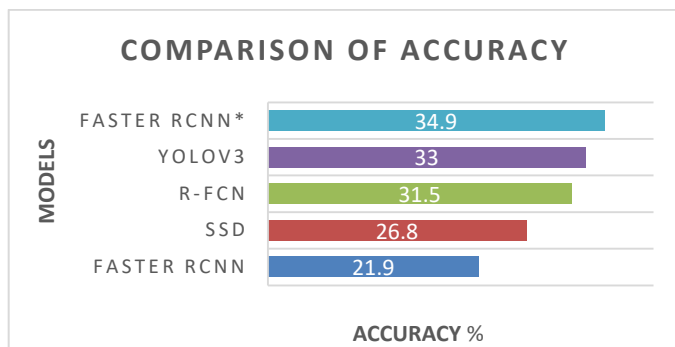


Fig. 5. Comparison of object detection models in term of accuracy coco dataset [48-49].

### D. Video Summary Generation Algorithm

The key collection process based on objects of interest in videos using the YOLOv3 deep learning model can be described mathematically as follows:

Let:

Vs be the collection of videos, it is denoted by $vs_i$, $i \in [1, n]$.

UO be the collection of desired object, it is denoted by $uo_j$, $j \in [1, m]$.

Fm($vs_i$) be the set of frames in video $v_i$, where each frame is denoted by $fm_{ik}$, $k \in [1, p]$.

The YOLOv3 model calculates the bounding-boxes ($b_{ik}$) and associated class-probabilities ($p_{ik}$) for each frame $fm_{ik}$ in the video $v_i$. The item's size, location, and bounding box coordinates (x, y, w, h) are displayed, and the likelihood that it belongs to a certain class is indicated by the class probabilities. Confidently selecting the frames that include interesting items is a necessary step in the key collection process. This may be achieved by setting a threshold for the class probability. The symbol α will be used to represent this threshold, where $0 \le \alpha \le 1$.

The mathematical method for key collection using YOLOv3 depending on desired object is defined below:

$$Key = \{(vs_{ik}, fm_{ik})|vs_{ik} \in Vs, fm_{ik} \in fm(vs_i), \exists\, uo_j \in O, p_{ik}(uo_j) \ge \alpha\} \quad (9)$$

where:

Key is the set of key frames containing user objects of interest. $p_{ik}(uo_j)$ represents the class probability of user object $uo_j$ in frame $fm_{ik}$.

In this equation, each video $vs_i$ and its frames $fm_{ik}$ are repeated a number of times. We include the video-frame pair ($vs_i$, $fm_{ik}$) in the set of key frames K if an object uoj appears in frame $fm_{ik}$ with a class probability $p_{ik}(uo_j)$ greater than or equal to the threshold. Additionally, to summarize the video using all crucial frames, we may alter the equation mentioned earlier as follows:

$$Smv = \{(vs_{ik}, fm_{ik})|vs_{ik} \in Vs, fm_{ik} \in fm(vs_i), \exists\, uo_j \in uO, p_{ik}(uo_i) \ge \beta\} \quad (10)$$

where:

Smv is the collection of frames containing interesting items whose class probabilities are larger than or equal to the summary threshold β, and where $0 \le \beta \le 1$.

Now that we have set a threshold on the class probabilities, we may collect n important frames and also summarize the video by looking at all frames that meet the threshold and include relevant elements. With these adjustments, the key frame collection procedure is more adaptable, and YOLOv3-based movie summaries are now possible. Utilizing the suggested architecture, the process for creating video summaries is depicted in Algorithm.

Algorithm : YOLOv3-Based Video Key Frame Selection and Summarization

| Algorithm: YOLOv3-Based Video Key Frame Selection and Summarization |
|---|
| **Input** |
| *Vs: Collection of videos (vs$_i$, i ∈ [1, n])* |
| *UO: Collection of desired objects (uo$_j$, j ∈ [1, m])* |
| *Fm(vs$_i$): Set of frames in video vs$_i$ (fm$_{ik}$, k ∈ [1, p])* |
| *α: Class probability threshold for key frame selection (0 ≤ α ≤ 1)* |
| *β: Class probability threshold for video summarization (0 ≤ β ≤ 1)* |
| **Output** |
| *Key: Set of key frames containing desired objects* |
| *Smv: Summarized collection of frames containing desired objects* |
| **Algorithm:** |
| *1. for* |
| *2. Initialize an empty set Key to store key frames.* |
| *3. Initialize an empty set Smv to store summarized video frames.* |
| *4. for* |
| *5.        Iterate over each video vs$_i$ in Vs:* |
| *6.        Iterate over each frame fm$_{ik}$ in Fm(vs$_i$):* |
| *7.        Load object detection model YOLOv3 on frame (fm$_{ik}$).* |
| *8.        For each detected object uo$_j$ with its corresponding class* |
| *9.                       pik(uo$_j$):* |
| *10.        **If** (pik(uo$_j$) ≥ α):* |
| *11.              Add the video-frame pair (vs$_i$, fm$_{ik}$) to set Key.* |
| *12.        **If** (pik(uo$_j$) ≥ β):* |
| *13.              Add the video-frame pair (vs$_i$, fm$_{ik}$) to set Smv.* |
| *13.        **else*** |
| *15.              Frame discarded* |
| *16.           **end if*** |
| *17.     **end for*** |
| *18.  **end for*** |
| *20. **Output [Sets Key and Smv]*** |

## IV. EXPERIMENTAL ANALYSIS AND RESULT

Python is used as the programming language, and all experiments are done on a computer with specifications such as an Intel Core i5 6th generation with 8 GB of RAM.

In this study, the effectiveness of the proposed method is assessed using a subjective technique. Each test stream has a summarized movie that is produced both manually (using the video editing application Davinci) and automatically using the proposed scheme. In simple terms, this is considered a frame-level comparison. Precision, recall, F1-score, and accuracy are used to assess the performance of the proposed method. The following equations provide the mathematical expressions for various evaluation parameters:

$$Precision(P) = \frac{TP}{TP+FP} \qquad (11)$$

$$Recall(R) = \frac{TP}{TP+FN} \qquad (12)$$

$$F1 - Score(F1) = \frac{2 \times P \times R}{P+R} \qquad (13)$$

$$Accuracy = \frac{TP+TN}{TP+FP+FN+TN} \qquad (14)$$

Two distinct datasets, the SumMe dataset and the author's dataset, are utilized to evaluate and compare the effectiveness of our approach with the manual method. 25 videos that have each had at least 15 human video tags are included in a video summarizing dataset called SumMe. The videos gathered from various sources are included in our own dataset. The videos

come in numerous sizes, including 320 x 240, 352 x 240, 640 x 360, 854 x 480, and 1920 x 1080, and are in the AVI and MP4 formats. The example test video sequences from the SumMe dataset and our self-created datasets are listed in Tables II and III, along with their parameters.

TABLE II.       SUMME DATASET STATISTICS

| Sr. No. | Sequences | Duration | No. of Frames |
|---|---|---|---|
| 1 | River Crossing | 408 sec | 10,200 |
| 2 | Playing ball | 104 sec | 3,120 |
| 3 | Kids playing | 106sec | 3,180 |
| 4 | St Maarten Landing | 70 sec | 1750 |
| 5 | Documentary1 | 74sec | 2220 |

The efficiency of our approach is assessed by a number of tests on video of various lengths and resolutions. The following sections discuss the evaluation of both datasets.

### A. Evaluation of SumMe dataset

For the evaluation of the SumME dataset, different scenarios have been taken from it, as mentioned in Table III. However, the first scenario belongs to a river crossing where several people are crossing the river. In which some of them have a handbag. So, in this scenario, collect all those scenes where a handbag (a user object of interest) appears.

TABLE III.       SELF CREATED DATASET STATISTICS

| Sr. No. | Sequences | Duration | No. of Frames |
|---|---|---|---|
| 1 | Car mirror breaking | 10 sec | 300 |
| 2 | Robbery | 7 sec | 210 |
| 3 | Dog Activity | 9 sec | 900 |
| 4 | Street video | 10  sec | 300 |
| 5 | Person Activity | 15 sec | 450 |

Similarly, the second scenario is related to playing ball, in which a dog is playing with the ball, so in this video, keep tracking all the movements of the dog. In kid's scenarios, a bicycle appears for a limited duration, so it is taken as an object of interest. In the next video, St. Martin is taken as UOoI, and the final video is related to the documentary Under Water, where people are searching for different things, so here the person is taken as UOoI. Fig. 6 describes these scenarios, and Fig. 7 shows the efficiency of our approach by presenting UOoI-detection shots.

*1) Results of SumMe dataset:* As can be seen, the proposed method showed tremendous results on the SumMe dataset. However, some frames can be falsely predicted as well as missed, as mentioned in Scenario 2 of Fig. 7. This is because of distortion in the video, so such frames can only be viewed with the naked eye. In the best case, like Scenario 5, all the frames are properly detected by the proposed method and achieve the highest accuracy. Fig. 8 shows the confusion matrices. The SumMe dataset results are mentioned in Table IV.

TABLE IV.  RESULT OF PROPOSEED METHOD ON SUMME DATASET

| Sr. No. | Scenarios | UOoI | Duration of Video | Duration of summary | P (%) | R (%) | F1 score (%) | Accuracy (%) |
|---|---|---|---|---|---|---|---|---|
| 1 | River Crossing | Handbag | 408 sec | 7.8 sec. | 100 | 79.5 | 88.64 | 98.82 |
| 2 | Playing ball | Dog | 104 sec | 20.17 sec. | 95.8 | 100 | 97.89 | 98.40 |
| 3 | Kids playing | Bicycle | 106sec | 8.02 sec. | 93.6 | 96.4 | 95.03 | 98.54 |
| 4 | St Maarten Landing | Airplane | 70 sec | 13.21 sec. | 100 | 100 | 100 | 100 |
| 5 | Documentary 1 | Person | 74sec | 4.13 sec. | 100 | 83.2 | 90.84 | 97.74 |
| | | | Total Time 762 seconds | Total video summary = 49.20 seconds (93.5%) | 97.8% | 91.8% | 94.48% | Overall accuracy 98.7% |

## B. Evaluation of Self Created Dataset

For the evaluation of the self-created dataset, different scenarios have been taken from online repositories, as mentioned in Table III. However, the first scenario belongs to a car mirror breaking, in which a person broke the car mirror and took the car from it, so the handbag is considered an object of interest. The second scene belongs to a robbery, so the person is taken as UOoI. The third scene is related to monitoring dog activity, so the dog is UOoI. In the fourth and fifth scenarios, bicycles and people are taken as UOoI. Fig. 9 describes these scenarios along with UOoI detection shots in order to show the efficiency of our method. Fig. 10 shows UOoI-based shot detection in order to show the efficiency of the proposed method.

*1) Result of self created dataset:* On a self-created dataset, as can be seen, the proposed strategy yields superior results. However, some frames can be falsely predicted as well as missed because of low resolution or low light in the video, so such frames can only be viewed with the naked eye. In the best case, like Scenarios 1, 3, and 5, all the frames are accurately detected by our method with the highest accuracy. The confusion matrices are shown in Fig. 11. Table V describes the result of the self-created dataset.



Fig. 6.  Sample shot of SumMe dataset.

TABLE V.  RESULT OF PROPOSEED METHOD ON SELF-CREATED DATASET

| Sr. No. | Scenarios | UOoI | Duration of Video | Duration of summary | P (%) | R (%) | F1 score (%) | Accuracy (%) |
|---|---|---|---|---|---|---|---|---|
| 1 | Car mirror breaking | Car | 10 sec | 10 sec. | 100 | 100 | 100 | 100 |
| 2 | Robbery | Person | 7 sec | 1.17 sec. | 100 | 100 | 100 | 100 |
| 3 | Dog Activity | Dog | 9sec | 1.07 sec. | 100 | 83.12 | 90.7 | 95.17 |
| 4 | Street video | Bicycle | 10 sec | 3.20 sec. | 100 | 82.7 | 90.5 | 92.48 |
| 5 | Person Activity | Person | 15 sec | 1.23 sec. | 100 | 100 | 100 | 100 |
| | | | Total Time 51 seconds | Total video summary = 16.67 seconds (67.3%) | 100% | 93.1% | 96.2% | Overall accuracy 97.5% |

Fig. 7.    Detection  of UOoI on SumMe dataset.



Fig. 8.    Confusion matrices of SumMe dataset.
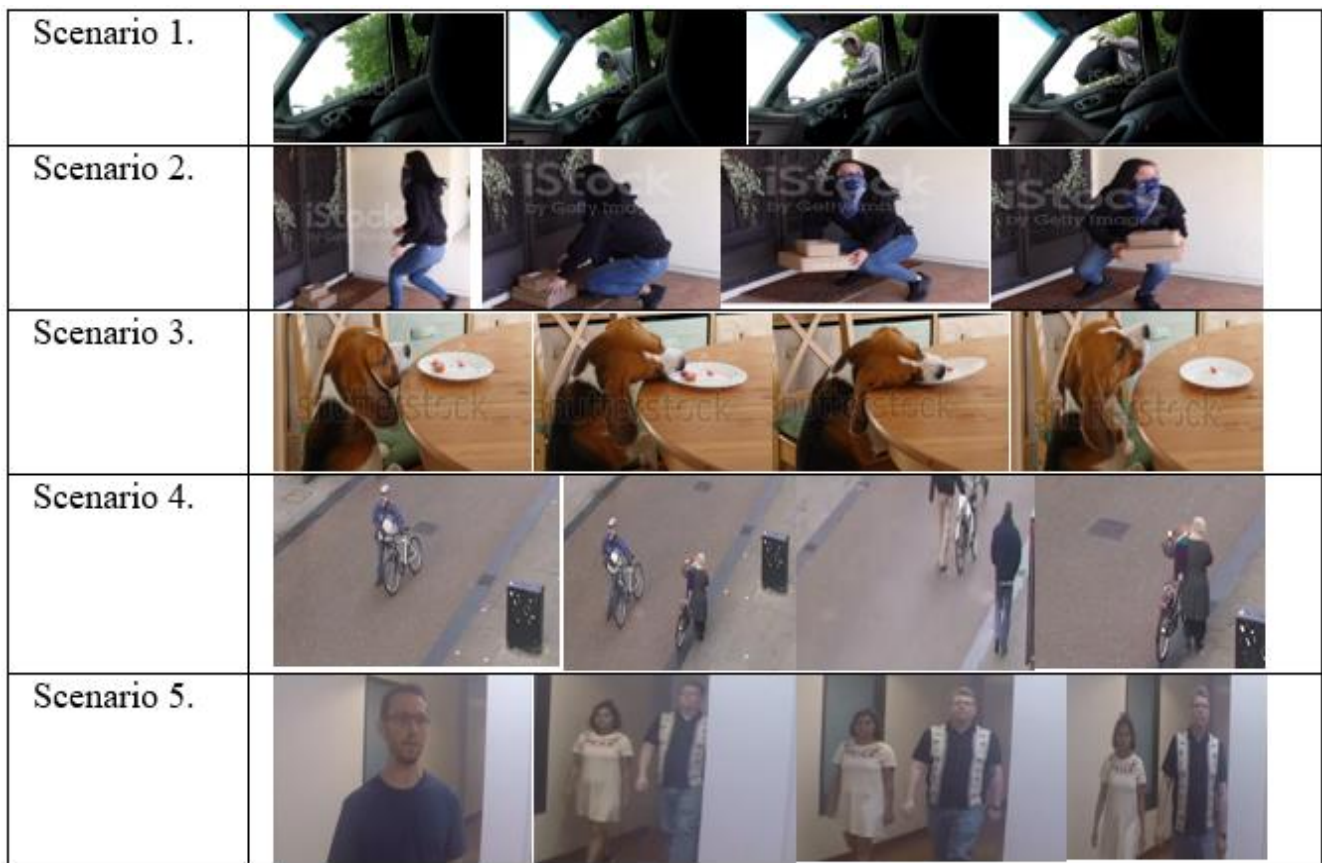
Fig. 9.    Sample shot of own dataset.



Fig. 10.  Detection of UOoI on self-created dataset.

Fig. 11. Confusion matrices of self created dataset.

## V. COMPARATIVE ANALYSIS

The comparative analysis of the proposed method with the existing state-of-the-art method is done in this section. The following core characteristics serve as the foundation for the comparison analysis:

- C1.Customised User object type (UOoI),
- C2. Frame Extraction based on UOoI,
- C3. Accuracy.
- C4: Rate of Summarization

Table VI demonstrates that the majority of the strategies now in use focus on the general detection of objects rather than one particular, specific object (UOoI). Similar to this, numerous algorithms extracted the video summary by eliminating unnecessary frames and scenes rather than concentrating on the objects. This research demonstrates that our method is distinctive in that it includes the most important qualities for VS. Like the proposed method, it considers the user's input to summarize the video and produce the output according to the user. So the proposed method extracted those frames that were in the region of the user's interest. Furthermore, the proposed method is more accurate and achieved 98.7% accuracy with the highest summarization rate of 93.5% as compared to existing state-of-the-art methods.

Table VII provides another comparison of the proposed work with the existing method.

TABLE VI. COMPARATIVE ANALYSIS WITH EXISTING METHODS BASED ON FACTORS

| Authors | C1 | C2 | C3 | C4 |
|---|---|---|---|---|
| Srinivas et al. [17] | ✗ | ✗ | ✗ | 1.8 % Improved block frame method |
| Ma at el. [9] | ✗ | ✗ | ✗ | 35%-48.28% |
| Varghese and Nair [8] | ✗ | ✗ | ✗ | 55% |
| Ngo et al. [33] | ✗ | ✗ | ✗ | 25% |
| Davila and Zanibbi.[32] | ✗ | ✓ | ✗ | 50% |
| Wang and Ngo [16] | ✗ | ✓ | 94% | 50% |
| **Proposed Model** | ✓ | ✓ | **98.7%** | **93.5%** |

TABLE VII.    ANALYSIS OF THE PROPOESED METHOD'S EFFICIENCY IN COMPARISON TO MODERN TECHNIQUES

| Authors | Precision (%) | Recall (%) | F1-Score (%) |
|---|---|---|---|
| FSM[16] | 40.73 | 54.43 | 46.59 |
| SVM[16] | 49.7 | 71.2 | 58.53 |
| A-HHMM[16] | 77.2 | 74.83 | 75.99 |
| DT[9] | 42.57 | 32.04 | 35.30 |
| STIMO[9] | 41.12 | 47.81 | 42.50 |
| VSUMM[9] | 50.43 | 45.34 | 46.51 |
| MSRa[9] | 40.03 | 52.05 | 43.56 |
| SOMP[9] | 41.83 | 55.02 | 45.33 |
| AGDS[9] | 41.35 | 58.40 | 46.27 |
| CRavg[9] | 44.94 | 56.44 | 48.28 |
| DSNET on SumMe[50] | 50.8 | 51.9 | 51.2 |
| **Proposed method on SumMe dataset** | **97.8** | **91.8** | **94.48** |
| **Proposed method on Self- created dataset** | **100** | **93.1** | **96.2** |

## VI.    GRAPHIC USER INTERFACE (GUI APPLICATION)

In the current study, a desktop application is also created utilizing PYQT5 and a Python-based GUI to give users an interactive interface for performing VS after finding objects. The interface of the application created for the selection of input video is shown in Fig. 12. Additionally, it does validation to verify the supplied input's format and contains information about the input. The system requires a video file in MP4 or AVI format as input. The explanation is that MP4 and AVI are both standardized file types. The application does not regard the input as a video if it has fewer than two frames. As a result, it issues a warning notice to the user. The next step is choosing the object type (UOoI) that will be recognized in the input video after the video has been chosen. There are several possibilities for choosing an object in this section. As a result, a user may choose UOoI with ease based on his or her preferences.
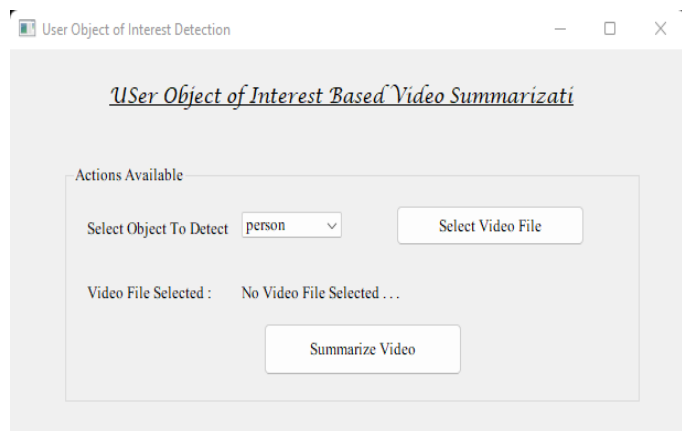


Fig. 12.  Graphical user interface.

## VII.    CONCLUSION AND FUTURE DIRECTION

This article provides a useful VS technique for summarizing videos using the UOoI. The proposed approach is notably more efficient, optimal, and quick as compared to current state-of-the-art techniques for summarizing the video. The UOoI-based solution increases the user's ability to reliably and flexibly construct the pertinent video summary. The proposed method can detect diverse object types accurately and efficiently using YOLOv3. The proposed approach is extensively tested on two different datasets, including the SumMe dataset and my personal dataset. The proposed approach achieves an accuracy of 98.7% with a quick processing rate and a time savings of 93.5% when the complete video is viewed to detect the UOoI on the SumME dataset. Accuracy is 97.5% on the self-created dataset, and overall time reductions are 67.3%. Similarly, a comparative analysis has been performed that shows the proposed work contains novelty with the highest accuracy as well as the highest summarization rate. Furthermore, a GUI that provides ease and configurable object selection is also developed. Future work on this project will expand it to include multiple objects of interest and concentrate on improving its accuracy and summary rate.

## REFERENCES

[1] E. Cosgrove, "One billion surveillance cameras will be watching around the world in 2021, a new study says. CNBC". https://www.cnbc.com/2019/12/06/one-billion-surveillance-cameras-will-be-watching-globally-in-2021.html (2019).

[2] Data generated by new surveillance cameras to increase exponentially in the coming years. SecurityInfoWatch.Com. https://www.securityinfowatch.com/video-surveillance/news/12160483/data-generated-by-new-surveillance-cameras-to-increase-exponentially-in-the-coming-years (2016).

[3] Duarte, F. T. Amount of Data Created Daily. https://explodingtopics.com/blog/data-generated-per-day (2023).

[4] L. Ceci, Statista, https://www.statista.com/statistics/259477/hours-of-video-uploaded-to-youtube-every-minute/.

[5] M. Furini, F. Geraci, M. Montangero, and M. Pellegrini, "STIMO: STIll and MOving video storyboard for the web scenario," Multimedia Tools Appl. vol. 46, no. 1, pp. 47–69 (2010).

[6] R. Kansagara, D. Thakore, M. Joshi, "A study on video summarization techniques". International journal of innovative research in computer and communication engi-neering, (2014).

[7] A. Bora, S. Sharma, "A Review on Video Summarization Approcahes: Recent Advances and Directions". In 2018 International Conference on Advances in Computing, Communication Control and Networking (ICACCCN), pp. 601-606 (2018).

[8] J. Varghese, K. R. Nair, "An Algorithmic Approach for General Video Summarization". In 2015 Fifth International Conference on Advances in Computing and Communications (ICACC), pp. 7-11 (2015).

[9] M. Ma, S. Mei, S. Wan, Z. Wang, D. D. "Feng. Robust video summarization using collaborative representation of adjacent frames". Multimedia Tools and Applications, 78(20), pp. 28985-29005 (2019).

[10] M. Miniakhmetova & M. Zymbler, "An approach to personalized video summarization based on user preferences analysis". In Application of Information and Communication Technologies (AICT), 2015 9th International Conference. pp. 153-155 (2015).

[11] Hafiz Burhan Ul Haq, M.Asif, Maaz Bin Ahmad, "Video Summarization Techniques: A Review", International Journal of Scientific & Technology Research, Vol. 9(11),(2020).

[12] S. Uchihachi, J. Foote, L. Wilcox, "Automatic Video Summarization Using a Measure of Shot Importance and a Frame Packing Method". United States Patent 6, pp.535-639 (2003).

[13] Z. Lu, K. Grauman, "Story-Driven Summarization for Egocentric Video". 2013 IEEE Conference on Computer Vision and Pattern Recognition, 2714–2721 (2013) [doi:org/10.1109/CVPR.2013.350].

[14] Y. Jiang, K. Cui, B. Peng, & C. Xu. Comprehensive Video Understanding: Video summarization with content-based video recommender design. In Proceedings of the IEEE/CVF International Conference on Computer Vision Workshops. (2019).

[15] P. K. Lai, M. Décombas, K. Moutet, R. Laganière, "Video summarization of surveillance cameras". In 2016 13th IEEE International Conference on Advanced Video and Signal Based Surveillance (AVSS,) pp. 286-294 (2016).

[16] F. Wang, C.W. Ngo, "Summarizing rushes videos by motion, object and event understanding". IEEE Transactions on Multimedia, (2012).

[17] M. Srinivas, M. M. Pai, & R. M. Pai, "An Improved Algorithm for Video Summarization–A Rank Based Approach". Procedia Computer Science. 89, pp. 812-819 (2016).

[18] K. Kumar, D. D Shrimankar. & N. Singh. "Event BAGGING: A novelevent summarization approach in multiview surveillance videos". In Innovations in Electronics, Signal Processing and Communication (IESC), 2017 International Conference, pp. 106-111, IEEE (2017).

[19] U. Damnjanovic, V. Fernandez, E. Izquierdo, "Event Detection and Clustering for Surveillance Video Summarization", In: Proceedings of the Ninth International Workshop on Image Analysis for Multimedia Interactive Services. IEEE Computer Society, Washington, USA (2008).

[20] S. S. Thomas, S. Gupta, V. K. Subramanian, "Perceptual video summarization—A new framework for video summarization". IEEE Transactions on Circuits and Systems for Video Technology. 27(8), pp. 1790-1802 (2016).

[21] F. Cricri, S. Mate, I. D. Curcio & M. Gabbouj. "Salient event detection in basketball mobile videos". In Multimedia (ISM), 2014 IEEE International Symposium, pp. 63-70, IEEE (2014).

[22] S.J. Andaloussi, A. Mohamed, N. Madrane & A. Sekkaki. "Soccer video summarization using video content analysis and social media streams". In Proceedings of the 2014 IEEE/ACM International Symposium on Big Data Computing, IEEE Computer Society,pp. 1-7 (2014).

[23] M. Cote, F. Jean, A. B. Albu & D. Capson. "Video summarization for remote invigilation of online exams". In Applications of Computer Vision (WACV), 2016 IEEE Winter Conference ,pp. 1-9, (2016)

[24] R. Agyeman, R.Muhammad, & G.S. Choi. "Soccer video summarization using deep learning". In 2019 IEEE Conference on Multimedia Information Processing and Retrieval (MIPR), pp. 270-273. IEEE. (2019).

[25] E. Bulut, T. Capin, "Key Frame Extraction from Motion Capture Data by Curve Saliency". In: Proceedings of 20th Annual Conference on Computer Animation and Social Agents, Belgium (2007).

[26] Tonge, A and Sudeep D. Thepade, "Creating Video Visual Storyboard with Static Video Summarization using Fractional Energy of Orthogonal Transforms" International Journal of Advanced Computer Science and Applications(IJACSA), 13(9), (2022). http://dx.doi.org/10.14569/IJACSA.2022.0130931.

[27] M. Ajmal, M. Naseer, F. Ahmad, A. Saleem. "Human Motion Trajectory Analysis Based Video Summarization". 2017 16th IEEE International Conference on Machine Learning and Applications (ICMLA), 0-103 (2017).

[28] Yasmin S. K. and Soudamini P., "Video Summarization: Survey on Event Detection and Summarization in Soccer Videos" International Journal of Advanced Computer Science and Applications(IJACSA), 6(11), 2015. http://dx.doi.org/10.14569/IJACSA.2015.061133.

[29] E. Apostolidis, E. Adamantidou, A.I. Metsai, V. Mezaris, and I. Patras, I.. Video Summarization Using Deep Neural Networks: A Survey. arXiv preprint arXiv:2101.06072. (2021).

[30] Al-Musawi, N.J. and Hasson S.T., "Improving Video Streams Summarization Using Synthetic Noisy Video Data" International Journal of Advanced Computer Science and Applications(IJACSA), 6(12), 2015. http://dx.doi.org/10.14569/IJACSA.2015.061233.

[31] A. A. Rav, Y. Pritch, S. Peleg, Making a long video short: Dynamic video synopsis. In 2006 IEEE Computer Society Conference on Computer Vision and Pattern Recognition (CVPR'06).vol. 1, pp. 435-441 (2006).

[32] K. Davila , R. Zanibbi. "Whiteboard Video Summarization via SpatioTemporal Conflict Minimization". In Document Analysis and Recognition (ICDAR), 2017 14th IAPR International Conference. vol 1. pp. 355-362(2017).

[33] C. W. Ngo, Y. F. Ma, H. J. Zhang, "Video summarization and scene detection by graph modeling". IEEE Transactions on circuits and systems for video technology, 15(2), pp. 296-305 (2005).

[34] M. Agrawal and D. S. Niranjan, "Video Summarization using Machine Learning Mechanism: A Comprehensive Review," 2021 International Conference on Advances in Technology, Management & Education (ICATME), Bhopal, India, 2021, pp. 31-36, doi: 10.1109/ICATME50232.2021.9732735.

[35] A. Tonge and S. D. Thepade, "A Novel Approach for Static Video Content Summarization using Shot Segmentation and k-means Clustering," 2022 IEEE 2nd Mysore Sub Section International Conference (MysuruCon), Mysuru, India, 2022, pp. 1-7, doi: 10.1109/MysuruCon55714.2022.9972379.

[36] K. Kumar, D.D. Shrimankar, N. Sing. "Equal partition based clustering approach for event summarization in videos". In: 2016 12th international conference on signal-image technology & internet-based systems (SITIS), IEEE, pp 119–126. (2016)

[37] K Kumar, D.D. Shrimankar, N. Singh, "Eratosthenes sieve based key-frame extraction technique for event summarization in videos". Multimed Tools Appl. 2018;77(6), pp. 7383–7404. doi: 10.1007/s11042-017-4642-9, (2018).

[38] [OFFICIAL] Wondershare Filmora - Easy, Trendy and Quality Video Editing Software. Filmora. Retrieved June 17, 2020, from https://filmora.wondershare.net/.

[39] OpenShot Studios, LLC. OpenShot Video Editor Free, Open, and Award-Winning Video Editor for Linux, Mac, and Windows! Openshot. Retrieved June 17, 2020, from https://www.openshot.org/.

[40] DaVinci Resolve logo June 22, 2023, from https://www.blackmagicdesign.com/products/davinciresolve/studio

[41] H. Meyer, P. Wei, & X. Jiang, "Intelligent Video Highlights Generation with Front-Camera Emotion Sensing". Sensors, 21(4), pp. 1035 (2021).

[42] M. Saqlain. "Sustainable Hydrogen Production: A Decision-Making Approach Using VIKOR and Intuitionistic Hypersoft Sets". Jounal of intellegent management decision, 2(3), pp. 130-138, (2023). https://doi.org/10.56578/jimd020303

[43] H. B. U. Haq, and M. Saqlain. "Iris detection for attendance monitoring in educational institutes amidst a pandemic: A machine learning approach." Journal of Industrial Intelligence, 1, no. 3, pp. 136-147, 2023.

[44] M. S. Afzal, & M.A. Tahir, "Reinforcement Learning based Video Summarization with Combination of ResNet and Gated Recurrent Unit". In VISIGRAPP (4: VISAPP), pp. 261-268 (2021).

[45] COCO - Common Objects in Context. COCO - Common Objects in Context. Retrieved July 1, 2020, from https://cocodataset.org/#home.

[46] A. Kathuria, What's new in YOLO v3? Towards Data Science. https://towardsdatascience.com/yolo-v3-object-detection-53fb7d3bfe6b (2018).

[47] J. Redmon, & A. Farhadi, "Yolov3: An incremental improvement". arXiv preprint arXiv:1804.02767, (2018).

[48] J. Hui, Object detection: speed and accuracy comparison (Faster R-CNN, R-FCN, SSD, FPN, RetinaNet and YOLOv3). Medium. https://medium.com/@jonathan_hui/object-detection-speed-and-accuracy-comparison-faster-r-cnn-r-fcn-ssd-and-yolo-5425656ae359 (2018).

[49] YOLO v3 theory explained, Medium. https://medium.com/analytics-vidhya/yolo-v3-theory-explained-33100f6d193 (2019).

[50] W. Zhu, J. Lu, J. Li, J. Zhou, "DSNet: A Flexible Detect-to-Summarize Network for Video Summarization." IEEE Transactions on Image Processing, pp. 948-962, 2020

# Enhanced System for Computer-Aided Detection of MRI Brain Tumors

Abdullah Alhothali, Ali Samkari, Umar S. Alqasemi*

Dept. of Electrical and Computer Engineering, King Abdulaziz University, Jeddah 21589, Saudi Arabia

*Abstract*—The categorization of brain images into normal or abnormal categories is a critical task in medical imaging analysis. In this research, we propose a software solution that automatically classifies MRI brain scans as normal or abnormal, specifically focusing on glioblastoma as an abnormal condition. The software utilizes first-order statistical features extracted from brain images and employs seven different classifiers, including Support Vector Machine (SVM) and K-Nearest Neighbors (KNN), for classification. The performance of the classifiers was evaluated using an open-source dataset, and our findings showed that SVM and KNN classifiers performed equally well in accurately categorizing brain scans. However, further improvements can be made by incorporating more images and features to enhance the accuracy of the classifier. The developed software has the potential to assist healthcare professionals in efficiently identifying abnormal brain scans, particularly in cases of glioblastoma, which could aid in early detection and timely intervention. Further research and development in this area could contribute to the advancement of healthcare technology and patient care.

*Keywords—Computer-aided detection; MRI; brain tumor; MATLAB; machine learning; support vector machine; KNN*

## I. PREFACE

Brain tumors are abnormal cell growths in the brain or the tissues around it. They can develop from several types of brain cells and can either be benign (non-cancerous) or malignant (cancerous). Patients may experience a variety of neurological symptoms and functional impairments as a result of brain tumors, which can have a serious influence on their health.

The National Cancer Institute (NCI) reports that only 1.4% of all new occurrences of cancer in the United States each year are caused by brain tumors, which makes them very uncommon. Unfortunately, they can have a terrible effect on patients' survival rates and quality of life. There has been a rise in the prevalence of brain tumors in recent years, with an estimated 87,720 new cases being diagnosed in the United States in 2021 [1].

Primary brain tumors and metastatic brain tumors are two broad categories of brain cancers. Primary brain tumors are those that develop inside the brain itself, and they can be further divided into groups according to the cells they originate from. The majority of primary brain tumors, gliomas, which arise from glial cells, make up roughly 81% of malignant brain tumors [2]. Meningiomas, which develop from the meninges (the brain's protective coverings), and pituitary tumors, which develop from the pituitary gland, are other primary brain tumor forms.

Based on their cellular features and aggressiveness, gliomas are further divided into distinct classes. Glioblastoma multiforme (GBM), commonly known as grade IV gliomas, is the most aggressive and malignant type of glioma and is regarded as the least aggressive [2]. Despite rigorous treatment methods, glioblastoma multiforme has a terrible prognosis with a median survival of only approximately 15 months [3].

The symptoms and treatment options of patients may be significantly impacted by the location of brain tumors within the brain, which can also vary. For instance, tumors in the cerebral hemispheres, which control motor, sensory, and cognitive abilities, might result in symptoms including seizures, weakness, language problems, and cognitive deficits. Other parts of the brain, such as the brainstem or cerebellum, can also develop tumors, which can result in deficiencies in the cranial nerves and symptoms including balance and coordination issues [2].

In conclusion, brain tumors can be benign or malignant abnormal cell growths in the brain or its surrounding tissues. They may develop from glial cells, meninges, and the pituitary gland, among other types of brain cells. Examples of primary brain tumors include gliomas, meningiomas, and pituitary tumors, whereas metastatic brain tumors are malignant cells that have traveled to the brain from other parts of the body. Patients who have brain tumors may have a variety of symptoms depending on where in the brain the tumor is located.

## II. INTRODUCTION

### A. Research Goals

The development of early detection and diagnostic tools is essential for enhancing patient outcomes in the case of brain tumors. The development of accurate and sensitive techniques for the early detection and identification of brain cancers should be the main emphasis of research. In order to achieve early identification and precise diagnosis of brain tumors, this may entail investigating cutting-edge image processing techniques. A better prognosis and better patient outcomes might result from early diagnosis, which enables prompt intervention and treatment. There are Computer Aided Detection (CADe) algorithms concerned with zero-one decision identifying normal from abnormal images. However, Computer Aided Diagnosis (CADx) algorithms can identify the type of malignancy within the image. In this research, we are developing a CADe system to identify normal from abnormal images; we are not investigating the type of malignancy.

### B. Literature Review

In a study by Kim et al, deep learning techniques were used to create a computer-aided detection (CAD) system for MRI brain cancers. The algorithm was trained using a dataset of 700 MRI brain scans, and the researchers were able to identify brain cancers with a remarkable 92.5% accuracy. For feature extraction and classification, they used the ResNet-50 convolutional neural network (CNN) architecture. The CAD system has shown encouraging results in helping radiologists quickly and reliably identifying brain cancers. The research by Kim et al shows how ResNet-50 CNN architecture, a deep learning system, can improve the identification of brain cancers in MRI scans. Their CAD system's excellent accuracy indicates that it might be an effective tool for radiologists in the early diagnosis of brain tumors, which might improve patient outcomes. The integration of CAD systems into clinical practice and the assessment of their effects on patient care could be the main topics of future study in this field [4].

Li et al Used a 3D deep convolutional neural network, proposed a CAD system for brain tumor segmentation in MRI data (DCNN). By using a dataset of 392 MRI scans to train their classifier, they were able to segment brain tumors with a high dice similarity coefficient of 0.91. They came to the conclusion that their 3D DCNN model has the potential to help radiologists in precise tumor segmentation for treatment planning because their CAD system performed better in tumor segmentation than other systems currently in use [5].

Dhara et al proposed a CAD system that combines region-based active contour and fuzzy clustering to segment brain tumors in MRI images. To segment MRI images and extract tumor patches, they used the region-based active contour model. Fuzzy clustering was then applied to further refine the tumor regions. Their CAD system outperformed other current techniques, achieving a high accuracy of 96.4% in tumor segmentation [6].

CAD system for brain tumor diagnosis in MRI images was proposed by Raza et al using a combination of machine learning and level set-based active contour. To categorize tumor locations taken from MRI images, they used machine learning methods like decision tree and SVM. Their CAD technology demonstrated promising results in detecting brain cancers with a 97.3% accuracy rate [7].

Patel and Patel (2020) conducted an extensive review on computer-aided detection/diagnosis (CAD) of brain tumor types in MRI images. The authors provided a comprehensive analysis of various computational methods and algorithmic strategies used in CAD systems, including traditional machine learning and deep learning models. They found that while the CAD systems showed promise in enhancing diagnostic accuracy, there were still significant challenges, including handling heterogeneous tumor shapes, sizes, and locations. The research highlights the need for enhanced CAD systems that can effectively address these challenges [8].

Chen et al. (2021) explored the efficacy of deep learning models for brain tumor classification and segmentation in MRI images. They noted that deep learning-based solutions outperformed traditional machine learning methods in terms of accuracy, efficiency, and generalizability. However, they pointed out the need for larger, more diverse datasets and more computing power to fully leverage deep learning's potential for CAD of brain tumors. This work underscores the significance of leveraging advanced machine learning architectures in the development of enhanced CAD systems [9].

Mallah et al. (2022) evaluated the potential of radiomics and machine learning for brain tumor classification. They found that combining radiomics features with machine learning models significantly improved the classification accuracy. However, the researchers also noted limitations, such as overfitting due to high dimensionality of radiomics features. This study suggests the need for CAD systems that integrate radiomics and machine learning while addressing potential limitations such as overfitting [10].

Dutta, Gupta, and Zisserman (2021) reviewed the role of artificial intelligence (AI) in the detection and classification of brain tumors. They noted that AI, particularly machine learning and deep learning, showed great potential for improving diagnostic speed and accuracy. However, they also highlighted the need for systems that can handle real-world variations and provide interpretability of the decision-making process. This work further supports the development of enhanced CAD systems that incorporate AI while addressing real-world variations and interpretability [11].

Bakas et al. (2022) discussed the challenges and opportunities in MRI brain tumor segmentation. They noted that despite the advancements in CAD systems, segmentation of brain tumors is still a challenging task due to the high variability of tumor appearance. They suggested the need for systems that can adapt to the variability of brain tumors and provide reliable and robust segmentation. This research underscores the need for enhanced CAD systems that can effectively segment brain tumors in MRI images [12].

In their study, Verma and Dev (2020) compared various machine learning techniques for MRI brain tumor classification. They revealed that while several techniques show promise, there is no one-size-fits-all solution, and the choice of technique depends on the specific characteristics of the dataset. They emphasized the need for systems that can choose the optimal technique based on the dataset characteristics. This study highlights the importance of adaptability in the design of enhanced CAD systems for MRI brain tumor detection [13].

Using MATLAB-based image processing techniques, several researches have suggested computer-aided detection (CAD) systems for finding brain tumors in MRI data. For instance, Moshavegh et al. created a CAD system that segmented tumor regions from MRI images using region growth and active contour methods in MATLAB, followed by morphological procedures for post-processing. Their CAD system demonstrated outstanding tumor segmentation accuracy of 94.6%, demonstrating the promise of MATLAB-based methods for precise tumor detection [14].

Similar to this, Jeyalakshmi et al. created a CAD system for classifying brain tumors utilizing feature extraction from MATLAB data and support vector machine (SVM)

classification. They used MATLAB to extract several image features—such as intensity, texture, and shape features—and trained an SVM classifier to recognize tumors. Their system successfully classified brain tumors with a high accuracy of 95.7%, illustrating the value of MATLAB-based methodologies for precise tumor classification [15].

In another paper, Shanthi and Kanmani proposed a CAD system for brain tumor detection in MRI images using MATLAB-based image processing techniques such as intensity-based thresholding, morphological operations [7], and feature extraction. To categorize tumor areas, they used pixel intensity and texture information extracted from MRI scans. Their CAD system identified brain tumors with an accuracy of 94.5%, demonstrating the potential of MATLAB-based techniques for precise tumor diagnosis [16].

Moreover, Shukla et al. suggested a CAD system for level set-based MATLAB-based brain tumor segmentation in MRI images. After extracting tumor regions from MRI images using the level set method in MATLAB, they processed the data with morphological procedures. Their CAD system successfully segmented tumors with a high accuracy of 96.3% [8], demonstrating the potency of the level-set method based on MATLAB for precise tumor detection [17].

Using magnetic resonance imaging (MRI) scans, Khan et al. (2019) created a computer-aided diagnostic (CAD) method for classifying brain tumors. Their system was built using a MATLAB implementation of a deep belief network (DBN), a subtype of deep neural network. Automatically extracting hierarchical features from MRI images was done using the DBN, and a classifier was trained to identify different types of tumors. The potential of DBNs for precise tumor classification is shown by the suggested system's accuracy of 92.4% in classifying brain tumors [18].

Convolutional neural networks (CNNs) and recurrent neural networks (RNNs), among other deep learning methods, were combined with MATLAB to create a CAD system by Choudhury et al. (2020) for the detection of brain tumors in MRI scans. CNNs are effective for image recognition jobs because they can automatically identify pertinent characteristics from unprocessed picture input. For modeling the dynamic changes in image sequences over time, RNNs, on the other hand, are built to capture temporal relationships in sequences of data. In this study, RNNs were used to predict the temporal progression of picture sequences, and CNNs were utilized to extract features from MRI scans. The proposed CAD system identified brain cancers with a high accuracy of 95.6%, demonstrating the value of deep learning algorithms for accurate tumor detection [19].

In MATLAB, Kumar et al. combined the watershed technique and k-means clustering to create a CAD system for segmenting brain tumors in MRI images. The common image segmentation algorithm K-means clustering involves assembling groupings of pixels with comparable brightness. On the other hand, the watershed algorithm is a method for improving the borders between various sections in an image. In this study, tumor regions from MRI scans were segmented using k-means clustering, and the watershed technique was then utilized to further refine the tumor borders. The proposed

CAD system successfully segmented tumors with a high accuracy of 95.2% [20].

From [21]-[25], these researches show how MATLAB may be used to create CAD systems for finding brain tumors in MRI images. The creation of precise and effective CAD systems to aid radiologists in the early detection and categorization of brain tumors is made possible by the robust and adaptable platform provided by MATLAB for image processing and machine learning. These studies have achieved great accuracy in tumor segmentation and classification using MATLAB-based algorithms, demonstrating the promise of MATLAB as a useful tool in the study of brain cancer.

In summary, several CAD systems have been proposed for brain tumor detection and classification using MRI images. These systems utilize various deep learning algorithms, such as deep belief networks (DBNs), convolutional neural networks (CNNs), recurrent neural networks (RNNs), as well as optimization algorithms like genetic algorithms (GAs), and clustering algorithms like fuzzy c-means and k-means clustering. These CAD systems demonstrate impressive accuracies ranging from 92.4% to 97.8% in accurately detecting and classifying brain tumors, indicating the potential of these approaches for improving the accuracy and efficiency of brain tumor diagnosis. Further research and development in this field hold promise for advancing the field of medical imaging and enhancing the clinical decision-making process in brain tumor diagnosis and treatment.

## III. METHODOLOGY

In this research paper, data of 167 brain images were analyzed using MATLAB. The analysis took place in five steps in order to discern the normal images from the abnormal ones. These steps are as shown in Fig. 1.
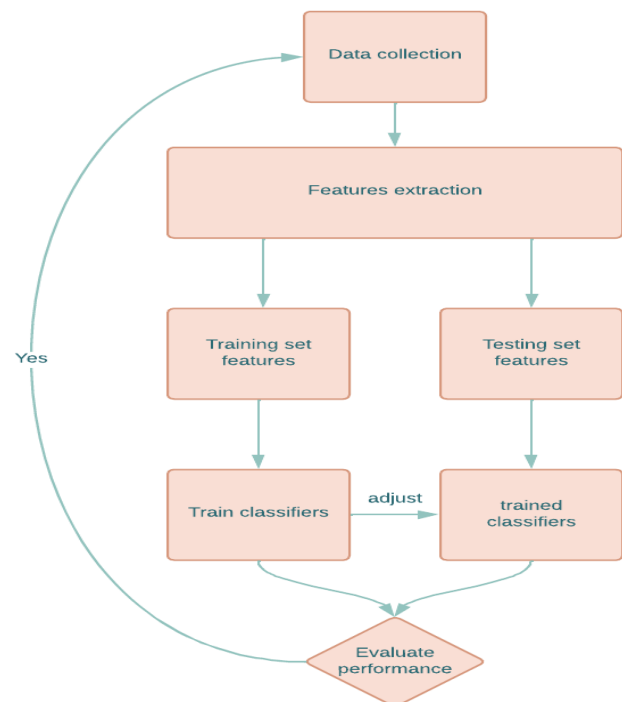


Fig. 1. Flowchart of proposed CAD system for brain tumor.

## A. Data Collection

The dataset was obtained from The Cancer Imaging Archive (TCIA) [26], which consists of 167 brain images that are well-suited for the research purpose. Out of these, 117 images were used for training, with 47 labeled as normal and 70 labeled as abnormal (brain tumor Glioblastoma). The remaining 50 images were used for testing, with 20 labeled as normal and 30 labeled as abnormal. The dataset is labeled, making it easy to interpret and use.

Fig. 2 shows a sample of tumor image, and a normal brain image. The dataset from TCIA contains a variety of images with different angles and views, which can be utilized for classification and feature extraction in the research process. It is open source and can be accessed online, with full details and descriptions available. The full dataset consists of 8798 images from 20 patients, providing a good number of images for analysis.
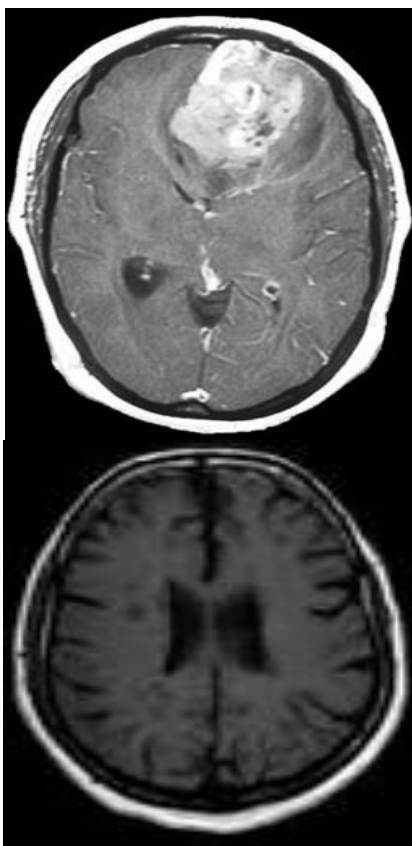


Fig. 2. Sample of MRI brain images. (top) brain tumor (bottom) normal brain.

## B. Feature Extraction

We want to choose features that might distinguish between benign and malignant conditions or those that are highly accurate, as well as those that do not correlate with disease and are not independent. Only first-order statistical features are taken into account in this study because they haven't been employed exclusively in other studies. The features that are employed are the absolute mean of the derivative of each image, the standard deviation of each image, and the mean of integration of the real images. Also, the same features were retrieved from the photos following a quick Fourier transformation. MATLAB functions like "mean," "std," "mode," "median," and "diff" are used to extract features.

The most noticeable color pixel and frequency of repetition in an image will be determined by the image's mean. The remaining pixels will depart from the mean brightness to a certain extent, as measured by the standard deviation. The derivative is then calculated and employed as a feature to determine which boosts abrupt variations in image brightness. Each type of tumor's retrieved features was plotted in a single figure. Each characteristic is derived from a compilation of photos taken from various perspectives and showing the same condition. Feature extraction from the combination of photos is then applied in the classification procedure.

## C. Classification

The next step in the process is to classify the data after choosing a database and extracting features from the database's photos. We utilize two methods to determine the classifier that performs best: Support vector machine (SVM) with four kernels (Linear, RBF, Polynomial Order2, and Order3), and k-voting nearest neighbor (KNN) classifiers are some examples of diverse classifier types [7]. The information is divided into two categories—normal and pathological brain images—in this step.

The classifier utilized in that software will have the highest accuracy among the roughly seven classifiers that will be employed and compared in this paper. SVM classifiers with discriminant functions of the types "RBF," "POLYNOMIAL," and "LINEAR" make up the classifiers. The remaining classifiers are KNN classifiers with k values of 1, 3, and 5.

## IV. Results and Discussion

Most of the research's findings are numerical. The accuracy of the image classification is the key criterion for the outcomes. The accuracy of the classifier's classification of the two brain states is the most crucial aspect that is being evaluated. The accuracy and error are the most crucial factors for the purpose of this research because they show how effective the classifier is. The TCIA datasets' MRI images were binarily categorized as benign vs. malignant instances by feature extractions; the two classifiers (support vector machine (SVM) and K-voting Nearest Neighbor (KNN)) were evaluated while the system was being trained on 70% of the datasets. Signal & Image Processing: The 11th issue of SIPIJ, published in February 2020 All of these operations were carried out using the MATLAB R2023b programmed, which was tested by 30%.

Furthermore, each classifier uses the same selected feature parameters, with the results displayed in Table I. The accuracy and error of the classifiers are shown in the table. These factors are crucial in choosing the optimal classifier to employ in such software or applications. Tables II and III show comparison of our results with the results of [21]-[25], the comparison is in terms of standard performance indicators including sensitivity, specificity, accuracy, error, and area under the curve (AUC) of the receiver operator characteristic (ROC). There is a very good enhancement in classifiers SVM Linear and KNN with K=5. Also, it shows similarities with the best results of other studies.

TABLE I.      RESULTS OF CLASSIFIERS

| Classifiers | KNN | | | SVM | | |
|---|---|---|---|---|---|---|
| | K1 | K3 | K5 | Liner | RBF | polynomial |
| Sensitivity | 100 | 96.3 | 95.9 | 97.3 | 100 | 100 |
| Specificity | 100 | 100 | 100 | 100 | 100 | 100 |
| Accuracy | 100 | 97.02 | 96.3 | 98.1 | 100 | 100 |
| Error | 0 | 2.98 | 3.7 | 1.9 | 0 | 0 |
| Auc | 100 | 96.1 | 95.4 | 97.1 | 100 | 100 |

TABLE II.      COMPARISON RESULTS WITH PREVIOUS STUDIES FOR SVM

| SVM Linear | | | | | |
|---|---|---|---|---|---|
| | sensitivity | specificity | Accuracy | Error | AUC |
| Dr. Umar Alqasmi [18] | 96.77 | 100 | 97.78 | 3.33 | 96.67 |
| Marwan Aldahami [19] | 100 | 100 | 100 | NA | 100 |
| Mohammed K. Bin jaah [20] | 50 | NA | 50 | 50 | NA |
| Loai Kinani [22] | 95 | 100 | 97.37 | 2.63 | 97.37 |
| Proposed Results | 97.3 | 100 | 98.1 | 1.9 | 97.1 |
| SVM RBF | | | | | |
| | sensitivity | specificity | Accuracy | Error | AUC |
| Dr. Umar Alqasmi [18] | 100 | 100 | 100 | 0 | 100 |
| Marwan Aldahami [19] | 100 | 100 | 100 | NA | 100 |
| Mohammed K. Bin jaah [20] | 100 | 100 | 100 | 0 | NA |
| Proposed Results | 100 | 100 | 100 | 0 | 100 |
| SVM Polynomial | | | | | |
| | sensitivity | specificity | Accuracy | Error | AUC |
| Dr. Umar Alqasmi [18] | 100 | 100 | 100 | 0 | 100 |
| Marwan Aldahami [19] | 100 | 96.43 | 98.15 | NA | 98.15 |
| Mohammed K. Bin jaah [20] | 50 | NA | 50 | 50 | NA |
| Eng. Anas Y. Saleh [21] | 100 | 100 | 100 | NA | NA |
| Loai Kinani [22] | 97.14 | 90.24 | 93.42 | 6.58 | 93.42 |
| Proposed Results | 100 | 100 | 100 | 0 | 100 |

TABLE III.      COMPARISON RESULTS WITH PREVIOUS STUDIES FOR KNN CLASSIFIER

| KNN K=1 | | | | | |
|---|---|---|---|---|---|
| | sensitivity | specificity | Accuracy | Error | AUC |
| Dr. Umar Alqasmi [18] | 100 | 100 | 100 | 0 | 100 |
| Marwan Aldahami [19] | 100 | 100 | 100 | NA | 100 |
| Mohammed K. Bin jaah [20] | 100 | 100 | 100 | 0 | NA |
| Eng. Anas Y. Saleh [21] | 90.91 | 100 | 95 | NA | NA |
| Proposed Results | 100 | 100 | 100 | 0 | 100 |

| KNN K=3 | | | | | |
|---|---|---|---|---|---|
| | sensitivity | specificity | Accuracy | Error | AUC |
| Dr. Umar Alqasmi [18] | 96.77 | 100 | 97.78 | 3.33 | 96.67 |
| Marwan Aldahami [19] | 100 | 100 | 100 | NA | 100 |
| Mohammed K. Bin jaah [20] | 100 | 64.52 | 72.5 | 27.5 | NA |
| Loai Kinani [22] | 82.5 | 86.11 | 84.21 | 15.79 | 84.21 |
| Proposed Results | 96.3 | 100 | 97.02 | 2.98 | 96.1 |
| KNN K=5 | | | | | |
| | sensitivity | specificity | Accuracy | Error | AUC |
| Dr. Umar Alqasmi [18] | 93.75 | 100 | 95.56 | 6.67 | 93.33 |
| Marwan Aldahami [19] | 100 | 100 | 100 | NA | 100 |
| Mohammed K. Bin jaah [20] | 100 | 64.52 | 72.5 | 27.5 | NA |
| Loai Kinani [22] | 81.4 | 90.91 | 85.53 | 14.47 | 85.53 |
| Proposed Results | 95.9 | 100 | 96.3 | 3.7 | 95.4 |

## V. CONCLUSIONS

The purpose of this research is to create software that automatically divides brain images into two categories. Images can be categorized as either normal or abnormal. The unique aspect of this study is that the program will distinguish between normal and abnormal brain scans. Glioblastoma is the only condition of the brain taken into consideration for this study. In this study, the created software was trained and tested using brain scans from an open source.

The features were then retrieved from the photos after further analysis. First order statistical features were taken into consideration in this investigation. The photos were classified using seven distinct classifiers in order to properly complete the investigation. To ensure that the most precise classifier is chosen, this was done. In addition to a KNN classifier, the classifiers included an SVM classifier. Our findings suggested that SVM and KNN classifiers were equally as accurate.

Future work can adopt more photos and the acquisition of more features is advised since this will undoubtedly improve the classifier's accuracy. Also, it is recommended to apply the method on some other disease like Alzheimer.

REFERENCES

[1] Brain and Other Central Nervous System Tumor Statistics, 2021, acsjournals.onlinelibrary.wiley.com/doi/10.3322/caac.21693. Accessed 10 June 2023.

[2] So, Jae-Seon et al. "Mechanisms of Invasion in Glioblastoma: Extracellular Matrix, Ca2+ Signaling, and Glutamate." Frontiers in cellular neuroscience vol. 15 663092. 2 Jun. 2021, doi:10.3389/fncel.2021.663092.

[3] Regev, Ohad et al. "Tumor-Treating Fields for the treatment of glioblastoma: a systematic review and meta-analysis." Neuro-oncology practice vol. 8,4 426-440. 20 Apr. 2021, doi:10.1093/nop/npab026.

[4] Kim et al., "Deep learning techniques for computer-aided detection of brain cancers in MRI scans," 2018.

[5] Li et al., "CAD system for brain tumor segmentation in MRI data using 3D deep convolutional neural network," 2018.

[6] Dhara et al., "CAD system for brain tumor segmentation in MRI images using region-based active contour and fuzzy clustering," 2017.

[7] Raza et al., "CAD system for brain tumor diagnosis in MRI images using machine learning and level set-based active contour," 2017.

[8] Patel A., & Patel A. "A Review on Computer-Aided Detection/Diagnosis of Brain Tumor Types in Magnetic Resonance Images" 2020.

[9] Deep Learning for Brain Tumor Classification and Segmentation in MRI Images. (Chen, H., Zhang, Y., Zhang, W., & Liao, H. 2021. Neurocomputing).

[10] Evaluation of Radiomics and Machine Learning for Brain Tumor Classification. (Mallah, R., Zhou, Z., & Plis, S. 2022. Journal of Medical Imaging).

[11] The Role of Artificial Intelligence in the Detection and Classification of Brain Tumors: An Overview. (Dutta, A., Gupta, A., & Zisserman, A. 2021. Neuro-Oncology).

[12] Challenges and Opportunities in MRI Brain Tumor Segmentation. (Bakas, S., Akbari, H., Sotiras, A., & Davatzikos, C. 2022. Journal of Digital Imaging).

[13] A Comparative Study of Machine Learning Techniques for MRI Brain Tumor Classification. (Verma, N., & Dev, S. 2020. IEEE Access).

[14] Moshavegh et al., "CAD system for brain tumor detection in MRI images using region growth and active contour in MATLAB," 2018.

[15] Jeyalakshmi et al., "CAD system for brain tumor classification using MATLAB-based feature extraction and support vector machine," 2019.

[16] Shanthi and Kanmani, "CAD system for brain tumor detection in MRI images using MATLAB-based image processing techniques," 2018.

[17] Shukla et al., "CAD system for brain tumor segmentation in MRI images using level set method in MATLAB," 2017.

[18] Khan et al., " method for brain tumor classification using deep belief network implemented in MATLAB," 2019.

[19] Choudhury et al., "Brain Tumor Detection and Classification Using Convolutional Neural Network and Deep Neural Network," International Conference on Computer Science, Engineering and Applications (ICCSEA) 2020.

[20] Kumar, Adesh. "Study and Analysis of Different Segmentation Methods for Brain Tumor MRI Application." Multimedia Tools and Applications, 2023, www.ncbi.nlm.nih.gov/pmc/articles/PMC9379244/.

[21] Dr. Umar Alqasmi, Ammar Alzuhair, & Abduallah Bama'bad, " ENHANCED SYSTEM FOR COMPUTER-AIDED DETECTION OF MRI BRAIN TUMORS" 2020.

[22] Marwan Aldahami & Umar Alqasemi, " CLASSIFICATION OF OCT IMAGES FOR DETECTING DIABETIC RETINOPATHY DISEASE USING MACHINE LEARNING" 2021.

[23] Mohammed K. Bin jaah, Abdullah Aljuhani, & Umar S. Alqasemi, " Characterization of liver Disease Based on Ultrasound Imaging System" 2021.

[24] Alqasemi, U., & Saleh, A. (2020). Computer Aided Diagnosis of Magnatic Resonance Brain Tumors Images with Automatic Segmentation. International Journal of Engineering Research and Technology, 9(12). https://www.ijert.org/research/computer-aided-diagnosis-of-magnatic-resonance-brain-tumors-images-with-automatic-segmentation-IJERTV9IS120156.pdf

[25] Loai Kinani & Umar Alqasemi, " Computer-Aided Diagnosis of Mammography Cancer" 2022.

[26] Brain Tumor Dataset. Retrieved from: https://public.cancerimagingarchive.net/nbia-search.

# Entanglement Classification for Three-qubit Pure Quantum System using Special Linear Group under the SLOCC Protocol

Amirul Asyraf Zhahir[1], Siti Munirah Mohd[2], Mohd Ilias M Shuhud[3], Bahari Idrus[4], Hishamuddin Zainuddin[5], Nurhidaya Mohamad Jan[6], Mohamed Ridza Wahiddin[7]

Faculty of Science and Technology, Universiti Sains Islam Malaysia, Negeri Sembilan, Malaysia[1, 3]
Kolej PERMATA Insan, Universiti Sains Islam Malaysia, Negeri Sembilan, Malaysia[2, 6]
Center for Artificial Intelligence Technology (CAIT), Faculty of Information Science and Technology,
Universiti Kebangsaan Malaysia, Selangor, Malaysia[4]
1133, Jalan S2 A33, Central Park, Seremban 2, Negeri Sembilan, Malaysia[5]
Tahmidi Centre, Universiti Sains Islam Malaysia, Negeri Sembilan, Malaysia[7]

*Abstract*—**Quantum technology has been introduced in the IR 4.0, breeding a new era of advanced technology revolutionizing the future. Hence, understanding the key resources of quantum technology, quantum entanglement is vital. Growing interests in quantum technologies has raised comprehensive studies of quantum entanglement, especially on the entanglement classification. Special Linear group, *SL(n)* of multipartite entanglement classification under the SLOCC protocol is not widely studied due to its complex structure, creating a curb in developing its classification method. Therefore, this paper developed and delivered a classification method of pure multipartite, three-qubit quantum state using a combination of Special Linear group, *SL(2)* x *SL(2)* x *SL(2)* model operator under the SLOCC, classifying entanglement using the model operator with certain selected parameters. Further analysis was done resulting in the determination of the six subgroups, namely fully separable (*A-B-C*), bi-separable (*A-BC*, *B-AC* and *C-AB*) and genuinely entangled (*W* and *GHZ*).**

*Keywords*—*Quantum entanglement; entanglement classification; three-qubit quantum system; special linear group; SL(2); stochastic local operations and classical communication; SLOCC*

## I. INTRODUCTION

The utilization of quantum entanglement is important in quantum computing, quantum cryptography, and quantum teleportation. This research main focus is the three-qubit quantum system entanglement classification as multipartite entanglement is considered complex and still an open problem [1, 2].

Quantum entanglement is one of the key resources in quantum information processing [3]. An entanglement can be described simply as multiple quantum subsystems states that cannot be described independently, regardless the distances between the subsystems [4]. To put it simply, an object's properties between two or more objects are dependent to each other. Over the years, quantum entanglement has sparked a massive interest of research in numerous fields namely quantum computing, quantum cryptography and quantum teleportation [5-15].

In quantum computing, the utilization of quantum entanglement principles would be a great power fuel [16, 17]. The concept of superposition and quantum bit also known as qubit is the core of a quantum computer. Yu [15] coined, superposition and qubit allows a quantum computer to process information at a significantly higher rate compared to its classical counterpart. It is reported that the most recent achievement made by one of the leader in the game, IBM quantum computer has exceeded over 1000 qubits and the organization has mapped their journey for the next few years [18].

Kumari and Adhikari [19] and Walter, et al. [20] has stated that in multipartite entanglement classification, there exists six inequivalent classes under Stochastic Local Operations and Classical Communication: One fully separable state ( $A-B-C$ ), three bi-separable state ( $A-BC$ , $B-AC$ , $C-AB$ ), and two genuinely entangled state ( $W$ and $GHZ$ ). To ensure a successful quantum information processing tasks, entanglement classifications is definitely a must.

In a three-qubit system classification, three main transformation protocols are Local Unitary (LU) protocol, Local Operations and Classical Communication (LOCC) protocol and Stochastic Local Operations and Classical Communication (SLOCC) protocol [21]. In this research, SLOCC protocol is utilized. According to Zha, et al. [22], SLOCC is the key in classifying higher dimensions qubit states and assists in dictating its entanglement within. However, Zha, et al. [22] added along with Lin and Wei [23], the entanglement classification can be challenging with a higher qubit quantum system mainly due to its infinite inequivalent SLOCC classes.

The classification of entanglement under the SLOCC protocol remains a significant challenge in multipartite entanglement. This event is still not well understood and rather complicated to be generally analysed [3, 20-22, 24-26]. Consequently, any transformed quantum state cannot be observed to execute the similar quantum information processing tasks [24].

The purpose of classifying entanglement under the SLOCC is to class the quantum states respectively to its tasks [21, 27, 28]. Two states $|\psi\rangle$ and $|\phi\rangle$ are SLOCC equivalent if both can execute a similar quantum information processing tasks [22]. According to M. Cunha, et al. [29], pure three-qubit GHZ and W states are non-equivalent under SLOCC. It means that it is unfeasible to transform a class state into another class state conversely. Li, et al. [30] stated SLOCC holds an advantage over LOCC that is SLOCC take on an uncomplicated mathematical form.

Research on a different group and protocol, namely Special Unitary group, $SU(n)$ under Local Unitary (LU) protocol has been conducted to unfold the issue in multipartite state transformation. Nevertheless, the classification of multipartite entanglement in Special Linear group, $SL(n)$ has its limitation in determining the particular quantum state classes as a consequence of the complexity of multipartite concept under SLOCC protocol [20, 31, 32]. Reason for this complication is that there are infinite number of SLOCC classes and the overlapping Special Linear group, $SL(n)$ subgroups [20, 31].

The main purpose of this research is to develop a straightforward multipartite entanglement classification model under the SLOCC protocol. This study employed Von Neumann entropy measurement, $S(\rho_i) = -\text{Tr}(\rho_i \ln \rho_i), \quad i = A, B, C$, specifically to detect an entanglement of the quantum states. The paper is organized as follows. The research methodology is detailed in Section II, followed by results and discussion in Section III and Section IV concludes the research.

## II. METHODOLOGY

The modeling process of the $SL(2) \times SL(2) \times SL(2)$ operator model included the following steps:

*1)* Understanding the measurement for $SL(2)$ parameterization. The variables of both the generator and parameters were thoroughly investigated at this stage.

*2)* Aligning the selected parameters with the used generator. This step established the parameter range to be used.

*3)* Developing the matrix for the operator model and implementing it in Mathematica 13.2.

*4)* The $SL(2) \times SL(2) \times SL(2)$ operator model full development. The process starts with combining the developed operator model with the initial pure quantum states to create a three-qubit quantum system.

Mathematica 13.2 software was chosen for its symbolic and numerical computations processing capabilities, making it suitable for simulations and mathematical modeling. It offers a powerful platform for creating and manipulating mathematical expressions and formulations, which is crucial for the development of the $SL(2) \times SL(2) \times SL(2)$ operator model.

Three parameters were selected and incorporated into the $SL(2) \times SL(2) \times SL(2)$ operator model because they have a significant influence on the correlated qubits:

*1)* The translation parameter *w* was represented within the range of $-\infty \to +\infty$, illustrating the position of a particle, which can take both positive and negative values.

*2)* The scaling parameter *r* was represented within the range of $0 \to +\infty$, illustrating the size of a particle, which can only take a positive value.

*3)* The rotation parameter *t* was represented within the range of $0 \to 2\pi$, illustrating the precise position of a particle within a plane.

The specific parameter values selected for every initial pure quantum state system are presented in the results section. Both operator model, $SL(2)$ and $SL(2) \times SL(2) \times SL(2)$ was developed in Mathematica 13.2. Fig. 1 shows the steps in developing the matrix for $SL(2) \times SL(2) \times SL(2)$ operator model.
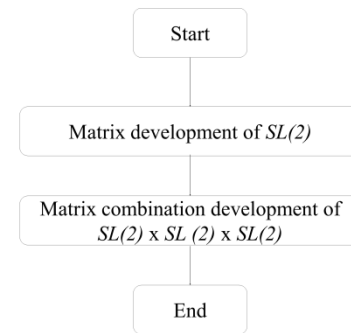


Fig. 1.    SL(2) x SL(2) x SL(2) operator model matrix development.

The development of the $SL(2)$ operator model began with the representation of $SL(2)$ as series expansions of exponential, cosine, and sine functions. The mathematical model was extended after completing the matrix development of the initial $SL(2)$ operator model. The $SL(2) \times SL(2) \times SL(2)$ model is designed to represent a multi-qubit quantum system, as the initial $SL(2)$ operator model only accounted for a single-qubit quantum system. The tensor product of $SL(2) \times SL(2) \times SL(2)$ operator model resulted in a large $8 \times 8$ composite matrix. Illustrated in Fig. 3 is the operator model for $SL(2) \times SL(2) \times SL(2)$. The $SL(2) \times SL(2) \times SL(2)$ operator model is denoted as $SL2$ from this point onward. The development went through several critical steps for its completion as illustrated in Fig. 2.

Fig. 2 shows the $SL2$ operator model in action on a fully separable quantum state, resulting in $SL2|000\rangle$. In this study, the $SL2$ operator model is also applied to bi-separable ($A-BC$) and genuinely entangled (*W* and *GHZ*) quantum states. The combination procedure of $SL2$ is illustrated in Fig. 4.
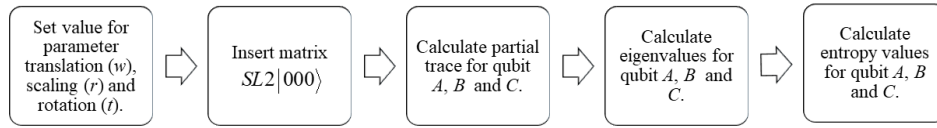
Fig. 2. SL(2) x SL(2) x SL(2) operator model development.

$$SL(2) = \begin{pmatrix} 2.718282\left(\cos[b1]\right) - i\sin[b1] & 0.3678794\left(\cos[b1]\right) - i\sin[b1] \\ 0 & 0.3678794\left(\cos[b1]\right) - i\sin[b1] \end{pmatrix}$$

$$SL(2) \otimes SL(2) \otimes SL(2) = \begin{pmatrix} 20.08554\left(\cos[b1] - i\sin[b1]\right)^3 & \dots & \dots & \dots & \dots & \dots & \dots & 0.049787\left(\cos[b1] - i\sin[b1]\right)^3 \\ 0 & \dots & \dots & \dots & \dots & \dots & \dots & 0.049787\left(\cos[b1] - i\sin[b1]\right)^2\left(\cos[b1] + i\sin[b1]\right) \\ 0 & \dots & \dots & \dots & \dots & \dots & \dots & 0.049787\left(\cos[b1] - i\sin[b1]\right)^2\left(\cos[b1] + i\sin[b1]\right) \\ 0 & \dots & \dots & \dots & \dots & \dots & \dots & 0.049787\left(\cos[b1] - i\sin[b1]\right)\left(\cos[b1] + i\sin[b1]\right)^2 \\ 0 & \dots & \dots & \dots & \dots & \dots & \dots & 0.049787\left(\cos[b1] - i\sin[b1]\right)^2\left(\cos[b1] + i\sin[b1]\right) \\ 0 & \dots & \dots & \dots & \dots & \dots & \dots & 0.049787\left(\cos[b1] - i\sin[b1]\right)\left(\cos[b1] + i\sin[b1]\right)^2 \\ 0 & \dots & \dots & \dots & \dots & \dots & \dots & 0.049787\left(\cos[b1] - i\sin[b1]\right)\left(\cos[b1] + i\sin[b1]\right)^2 \\ 0 & \dots & \dots & \dots & \dots & \dots & \dots & 0.049787\left(\cos[b1] + i\sin[b1]\right)^3 \end{pmatrix}$$

Fig. 3. SL(2) x SL(2) x SL(2) operator model.
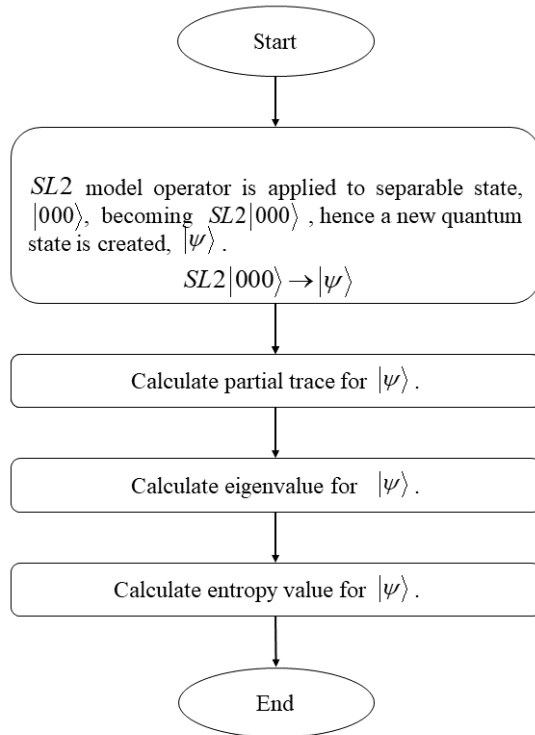


Fig. 4. SL 2 operator model combination procedure.

## III. RESULTS AND DISCUSSION

As shown in Fig. 4, the $SL2$ operator model is applied to a fully separable quantum state, resulting in a new combined quantum state denoted as $|\psi\rangle$. It was also applied to bi-separable ($A-BC$) as well as genuinely entangled ($W$ and $GHZ$) quantum states. Each quantum state was simulated using two sets of translation and scaling values, each of which contained 24 rotation values. The simulations provide valuable insights into the characteristics of the quantum states when acted upon by the operator model under various values of translation, scaling, and rotation.

The translation parameter was selected within the range of $-\infty \rightarrow +\infty$ while the scaling parameter is selected within the range of $0 \rightarrow +\infty$. The rotation angle parameters were determined and selected within $0 \rightarrow 2\pi$, which encompassed all four quadrants of the Cartesian plane. There are two main case simulations: Case 1 and Case 2. In each case, the translation and scaling values were fixed while different rotation angles were used. Table I shows the values used for translation and scaling, while Table II shows the values used for rotation.

TABLE I. TRANSLATION (*W*) AND SCALING (*R*) PARAMETERS

| Case | Parameters |
|---|---|
| 1 | $w = 1, r = 1$ |
| 2 | $w = -1, r = \frac{1}{2}$ |

The classification process was influenced by the values of all three parameters, as listed in Table I and II. The von Neumann entropy is given by $S(\rho_i) = -\mathrm{Tr}(\rho_i \ln \rho_i), \quad i = A, B, C$. The value of this entropy range between $0 \pounds S(r) \pounds 1$ for all density matrix $r$, with 0 indicating a fully separable quantum state and 1 indicating the maximum value of entanglement. These values enable us to observe the degree of entanglement for specific quantum states and further classify them based on the parameter combinations used in each simulation.

The simulation's initial quantum states cover four out of six entanglement classes under the SLOCC protocol: fully separable ($A-B-C$), bi-separable ($A-BC$, $B-AC$, $C-AB$), and genuinely entangled ($W$ and $GHZ$). The other two classes of bi-separable ($B-AC$ and $C-AB$) were not considered separately because their attributes are similar and can be represented by the $A-BC$ class. The combination of these initial quantum states with the operator model generated a new quantum state, representing the combination after the transformation. The new quantum state was then acted upon by three selected parameters: translation, scaling, and rotation.

Table III summarizes the classification of pure three-qubit entanglement simulations for fully separable, bi-separable, and genuinely entangled states using a special linear group under the SLOCC protocol and the von Neumann entropy measurement. The study successfully classified pure three-

qubit entanglement of the initial quantum states as fully separable, bi-separable, and genuinely entangled. The simulations revealed that the final quantum state remained unchanged from the initial quantum state in some cases, while the parameter selection manipulation changed the final quantum state in others. The simulation results demonstrated that the entanglement class of a quantum state can be altered or maintained by controlling the translation, scaling, and rotation parameters while adhering to the SLOCC protocol. This demonstrates the significance of these parameters in influencing the entanglement properties of a quantum system.

TABLE II. ROTATION (*T*) PARAMETERS

| Quadrant | Angle (π) | Angle (°) |
|---|---|---|
| 1st | $\frac{\pi}{2}$ | 90 |
| | $\frac{\pi}{4}$ | 45 |
| | $\frac{\pi}{6}$ | 30 |
| | $\frac{\pi}{8}$ | 22.5 |
| | $\frac{\pi}{10}$ | 18 |
| | $\frac{\pi}{12}$ | 15 |
| 2nd | $\pi$ | 180 |
| | $\frac{3\pi}{4}$ | 135 |
| | $\frac{5\pi}{6}$ | 150 |
| | $\frac{7\pi}{8}$ | 157.5 |
| | $\frac{9\pi}{10}$ | 162 |
| | $\frac{11\pi}{12}$ | 165 |
| 3rd | $\frac{3\pi}{2}$ | 270 |
| | $\frac{5\pi}{4}$ | 225 |
| | $\frac{7\pi}{6}$ | 210 |
| | $\frac{9\pi}{8}$ | 202.5 |
| | $\frac{11\pi}{10}$ | 198 |
| | $\frac{13\pi}{12}$ | 195 |
| 4th | $2\pi$ | 360 |
| | $\frac{7\pi}{4}$ | 315 |
| | $\frac{11\pi}{6}$ | 330 |
| | $\frac{15\pi}{8}$ | 337.5 |
| | $\frac{19\pi}{10}$ | 342 |
| | $\frac{23\pi}{12}$ | 345 |

TABLE III.    PURE THREE-QUBIT ENTANGLEMENT CLASSIFICATION

| Initial Quantum State | Case | Rotation ($t$) | Final Quantum State |
|---|---|---|---|
| A-B-C | 1 | $\frac{\pi}{2}, \frac{\pi}{4}, \frac{\pi}{6}, \pi, \frac{5\pi}{6}, \frac{7\pi}{8}, \frac{9\pi}{10}, \frac{11\pi}{12}, \frac{3\pi}{2}, \frac{7\pi}{6}, \frac{9\pi}{8}, \frac{11\pi}{10}, \frac{13\pi}{12}, \frac{7\pi}{4}, \frac{11\pi}{6}$ | A-B-C |
| | 2 | $\frac{\pi}{2}, \frac{\pi}{4}, \frac{\pi}{6}, \pi, \frac{5\pi}{6}, \frac{7\pi}{8}, \frac{9\pi}{10}, \frac{11\pi}{12}, \frac{3\pi}{2}, \frac{7\pi}{6}, \frac{9\pi}{8}, \frac{11\pi}{10}, \frac{13\pi}{12}, \frac{7\pi}{4}, \frac{11\pi}{6}$ | |
| A-BC | 1 | $\frac{\pi}{2}, \frac{\pi}{4}, \frac{5\pi}{6}, \frac{7\pi}{8}, \frac{9\pi}{10}, \frac{11\pi}{12}, \frac{3\pi}{2}, \frac{7\pi}{6}, \frac{9\pi}{8}, \frac{11\pi}{10}, \frac{13\pi}{12}$ | A-B-C |
| | | $\frac{7\pi}{4}$ | A-BC |
| | 2 | $\frac{\pi}{2}, \frac{3\pi}{4}, \frac{5\pi}{6}, \frac{3\pi}{2}, \frac{5\pi}{4}, \frac{7\pi}{6}$ | A-B-C |
| | | $\frac{\pi}{10}, \frac{\pi}{12}, \frac{7\pi}{8}, \frac{9\pi}{8}, 2\pi, \frac{15\pi}{8}, \frac{19\pi}{10}, \frac{23\pi}{12}$ | A-BC |
| W | 1 | $\frac{\pi}{2}, \pi, \frac{3\pi}{4}, \frac{5\pi}{6}, \frac{7\pi}{8}, \frac{9\pi}{10}, \frac{11\pi}{12}, \frac{3\pi}{2}, \frac{5\pi}{4}, \frac{7\pi}{6}, \frac{9\pi}{8}, \frac{11\pi}{10}, \frac{13\pi}{12}$ | A-BC |
| | 2 | $\frac{\pi}{2}, \pi, \frac{3\pi}{4}, \frac{5\pi}{6}, \frac{7\pi}{8}, \frac{9\pi}{10}, \frac{11\pi}{12}, \frac{3\pi}{2}, \frac{5\pi}{4}, \frac{7\pi}{6}, \frac{9\pi}{8}, \frac{11\pi}{10}, \frac{13\pi}{12}$ | A-B-C |
| | | $\frac{\pi}{4}, \frac{\pi}{6}, \frac{\pi}{8}, \frac{\pi}{10}, \frac{\pi}{12}, 2\pi, \frac{7\pi}{4}, \frac{11\pi}{6}, \frac{15\pi}{8}, \frac{19\pi}{10}, \frac{23\pi}{12}$ | GE |
| GHZ | 1 | $\frac{\pi}{4}, \pi, \frac{7\pi}{8}, \frac{9\pi}{10}, \frac{11\pi}{12}, \frac{9\pi}{8}, \frac{11\pi}{10}, \frac{13\pi}{12}, \frac{7\pi}{4}$ | A-B-C |
| | | $\frac{\pi}{6}, \frac{7\pi}{6}$ | GE |
| | 2 | $\frac{\pi}{2}, \frac{\pi}{4}, \frac{\pi}{6}, \pi, \frac{5\pi}{6}, \frac{7\pi}{8}, \frac{9\pi}{10}, \frac{11\pi}{12}, \frac{3\pi}{2}, \frac{7\pi}{6}, \frac{9\pi}{8}, \frac{11\pi}{10}, \frac{13\pi}{12}, \frac{7\pi}{4}, \frac{11\pi}{6}$ | A-B-C |
| | | $\frac{\pi}{8}, \frac{15\pi}{8}$ | GE |

## IV. CONCLUSION

This study focused on the entanglement classification of the pure three-qubit quantum system using a novel mathematical operator model $SL2$ based on the special linear group principles under the SLOCC protocol. The $SL2$ operator model derived was successfully developed using Mathematica.

The utilization of special linear group definitely has its advantage over special unitary group, as it can principally increase and decrease the degree of entanglement of the quantum systems, while special unitary group maintains the entanglement of quantum states. The simulations resulted in the entanglement classification of the three-qubit quantum system into fully separable ($A-B-C$), bi-separable ($A-BC$), and genuinely entangled ($GE$) states, which were validated with previous studies to demonstrate the success of the developed operator model.

Additionally, the operator model has the potential to be extended to entanglement classification for mixed quantum states for three-qubit quantum systems. Valuable conclusions about the effects of parameter manipulation on entanglement states can be drawn, contributing to a better understanding of quantum entanglement and its potential applications in quantum information processing.

## REFERENCES

[1] Sun, Yize, Lin Chen, and Li-Jun Zhao. "Tripartite genuinely entangled states from entanglement-breaking subspaces". Journal of Physics A: Mathematical and Theoretical, 54 No. 2 (2020): p. 025303 https://doi.org/10.1088/1751-8121/abce20.

[2] Wu, Qi-Feng. "Entanglement Classification via Operator Size: a Monoid Isomorphism". arXiv preprint arXiv:2111.07636, No. (2022): p.

[3] Jaffali, Hamza, and Frédéric Holweck. "Quantum entanglement involved in Grover's and Shor's algorithms: the four-qubit case". Quantum Information Processing, 18 No. 5 (2019): p. 133 https://doi.org/10.1007/s11128-019-2249-y.

[4] Guo, Yuying. "Introduction to quantum entanglement". AIP Conference Proceedings, 2066 No. 1 (2019): p. 020009 https://doi.org/10.1063/1.5089051.

[5] Kirsanov, N. S., V. A. Pastushenko, A. D. Kodukhov, M. V. Yarovikov, A. B. Sagingalieva, D. A. Kronberg, M. Pflitsch, and V. M. Vinokur. "Forty thousand kilometers under quantum protection". Scientific Reports, 13 No. 1 (2023): p. 8756 https://doi.org/10.1038/s41598-023-35579-6.

[6] Erkılıç, Ö, L. Conlon, B. Shajilal, S. Kish, S. Tserkis, Y. S. Kim, P. K. Lam, and S. M. Assad. "Surpassing the repeaterless bound with a photon-number encoded measurement-device-independent quantum key distribution protocol". npj Quantum Information, 9 No. 1 (2023): p. https://doi.org/10.1038/s41534-023-00698-5.

[7] Chen, Z., X. Wang, S. Yu, Z. Li, and H. Guo. "Continuous-mode quantum key distribution with digital signal processing". npj Quantum Information, 9 No. 1 (2023): p. https://doi.org/10.1038/s41534-023-00695-8.

[8] Perepechaenko, M., and R. Kuang. "Quantum encryption of superposition states with quantum permutation pad in IBM quantum computers". EPJ Quantum Technology, 10 No. 1 (2023): p. https://doi.org/10.1140/epjqt/s40507-023-00164-3.

[9] Andronikos, Theodore, and Alla Sirokofskich. "An Entanglement-Based Protocol for Simultaneous Reciprocal Information Exchange between 2 Players". Electronics, 12 No. 11 (2023): p. 2506 https://doi.org/https://doi.org/10.3390/electronics12112506.

[10] Li, Zhenghua, Xiangyu Wang, Ziyang Chen, Tao Shen, Song Yu, and Hong Guo. "Impact of non-orthogonal measurement in Bell detection on continuous-variable measurement-device-independent quantum key distribution". Quantum Information Processing, 22 No. 6 (2023): p. 236 https://doi.org/10.1007/s11128-023-03993-4.

[11] Li, Fulin, Tingyan Chen, and Shixin Zhu. "A (t, n) Threshold Quantum Secret Sharing Scheme with Fairness". International Journal of Theoretical Physics, 62 No. 6 (2023): p. 119 https://doi.org/10.1007/s10773-023-05383-z.

[12] Tan, Yongjian, Liang Zhang, Tianxing Sun, Zhihua Song, Jincai Wu, and Zhiping He. "Polarization compensation method based on the wave plate group in phase mismatch for free-space quantum key distribution". EPJ Quantum Technology, 10 No. 1 (2023): p. 6 https://doi.org/10.1140/epjqt/s40507-023-00163-4.

[13] Shen, Si, Chenzhi Yuan, Zichang Zhang, Hao Yu, Ruiming Zhang, Chuanrong Yang, Hao Li, Zhen Wang, You Wang, Guangwei Deng, Haizhi Song, Lixing You, Yunru Fan, Guangcan Guo, and Qiang Zhou. "Hertz-rate metropolitan quantum teleportation". Light: Science & Applications, 12 No. 1 (2023): p. 115 https://doi.org/10.1038/s41377-023-01158-7.

[14] Haddadi, Saeed, and Mohammad Bohloul. "A Brief Overview of Bipartite and Multipartite Entanglement Measures". International Journal of Theoretical Physics, 57 No. (2018): p. 3912–16 https://doi.org/10.1007/s10773-018-3903-3.

[15] Yu, Yue. "Advancements in Applications of Quantum Entanglement". Journal of Physics: Conference Series, 2012 No. 1 (2021): p. 012113 https://doi.org/10.1088/1742-6596/2012/1/012113.

[16] Pan, Jie. "Characterizing true quantum computing power". Nature Computational Science, 1 No. 1 (2021): p. 15-15 https://doi.org/10.1038/s43588-020-00018-3.

[17] Asif, Naema, Uman Khalid, Awais Khan, Trung Q. Duong, and Hyundong Shin. "Entanglement detection with artificial neural networks". Scientific Reports, 13 No. 1 (2023): p. 1562 https://doi.org/10.1038/s41598-023-28745-3.

[18] "The IBM Quantum Development Roadmap." 2023, https://www.ibm.com/quantum/roadmap.

[19] Kumari, Anu, and Satyabrata Adhikari. "Classification witness operator for the classification of different subclasses of three-qubit GHZ class". Quantum Information Processing, 20 No. 9 (2021): p. 316 https://doi.org/10.1007/s11128-021-03250-6.

[20] Walter, Michael, David Gross, and Jens Eisert. "Multi-partite entanglement". No. (2017): p.

[21] Li, Dafa. "Stochastic local operations and classical communication (SLOCC) and local unitary operations (LU) classifications of n qubits via ranks and singular values of the spin-flipping matrices". Quantum Information Processing, 17 No. (2018): p. https://doi.org/10.1007/s11128-018-1900-3.

[22] Zha, Xinwei, Irfan Ahmed, Da Zhang, Wen Feng, and Yanpeng Zhang. "Stochastic local operations and classical communication invariants via square matrix". Laser Physics, 29 No. (2019): p. 025203 https://doi.org/10.1088/1555-6611/aaf637.

[23] Lin, Lijinzhi, and Zhaohui Wei. "Testing multipartite entanglement with Hardy's nonlocality". Physical Review A, 101 No. 5 (2020): p. 052118 https://doi.org/10.1103/PhysRevA.101.052118.

[24] Li, Dafa. "SLOCC classification of n qubits invoking the proportional relationships for spectrums and standard Jordan normal forms". Quantum Information Processing, 17 No. 1 (2017): p. 1 https://doi.org/10.1007/s11128-017-1770-0.

[25] Aulbach, Martin. "Symmetric entanglement classes for n qubits". arXiv preprint arXiv:1103.0271, No. (2011): p.

[26] Dietrich, Heiko, Willem A De Graaf, Alessio Marrani, and Marcos Origlia. "Classification of four qubit states and their stabilisers under SLOCC operations". Journal of Physics A: Mathematical and Theoretical, No. (2022): p. https://doi.org/https://doi.org/10.1088/1751-8121/ac4b13.

[27] Backens, Miriam. "Number of superclasses of four-qubit entangled states under the inductive entanglement classification". Physical Review A, 95 No. 2 (2017): p. 022329 https://doi.org/10.1103/PhysRevA.95.022329.

[28] Kumari, Anu, and Satyabrata Adhikari. "Classification witness operator for the classification of different subclasses of three-qubit GHZ class". Quantum Information Processing, 20 No. (2021): p. https://doi.org/10.1007/s11128-021-03250-6.

[29] M. Cunha, Márcio, Alejandro Fonseca, and Edilberto O. Silva. "Tripartite Entanglement: Foundations and Applications". Universe, 5 No. 10 (2019): p. 209

[30] Li, Yinan, Youming Qiao, Xin Wang, and Runyao Duan. "Tripartite-to-Bipartite Entanglement Transformation by Stochastic Local Operations and Classical Communication and the Structure of Matrix Spaces". Communications in Mathematical Physics, 358 No. 2 (2018): p. 791-814 https://doi.org/10.1007/s00220-017-3077-5.

[31] Gharahi, Masoud, Stefano Mancini, and Giorgio Ottaviani. "Fine-structure classification of multiqubit entanglement by algebraic geometry". Physical Review Research, 2 No. 4 (2020): p. 043003 https://doi.org/10.1103/PhysRevResearch.2.043003.

[32] Burchardt, Adam, and Zahra Raissi. "Stochastic local operations with classical communication of absolutely maximally entangled states". Physical Review A, 102 No. (2020): p.

# Dance Motion Detection Algorithm Based on Computer Vision

YanWang[1], Zhiguo Wu[2]

EIT Data Science and Communication College, Zhejiang Yuexiu University, Shaoxing 312000, Zhejiang, China[1]

School of Art, Zhejiang Yuexiu University, Shaoxing 312000, Zhejiang, China[2]

*Abstract*—**Human posture recognition is an essential link in the development of human-computer interaction. Currently, the existing dance movement training methods often require students to constantly watch videos or find a tutor to correct them during practice to achieve good results, which not only takes a lot of time and energy but also creates some difficulties and challenges for students. The research goal of this paper was to use computer recognition technology to detect dance movements and identify body postures. This paper develops a Kinect dance auxiliary training system based on the body skeleton tracking technology of the Kinect 3D sensor, combined with auxiliary dance training. This article not only introduced a fixed axis-based expression method for joint angles to improve the stability of joint angles but also improved the body position detection algorithm using the angle of joint spots to realize the accurate recognition of human body posture. In the experiment, the trainee's arm was raised to the highest position, which could not meet the requirements, and the trainer's wrist should be raised by another 200 mm. Moreover, retracting the hand was too fast, which did not meet the standard action. The test results showed that the system could effectively improve the dance movements of the students.**

*Keywords—Dance motion detection; computer vision; human posture recognition; Kinect 3D sensor*

## I. INTRODUCTION

Dance is a captivating and culturally significant form of expression that has gained popularity not only in the realm of entertainment but also in educational and daily life contexts. Achieving excellence in dance requires rigorous adherence to standards, often necessitating the guidance of specialized instructors. However, the subjective nature of human judgment and the lack of standardized guidance in dance practice present challenges for learners. Furthermore, relying solely on expert feedback can limit the flexibility and accessibility of dance training. This underscores the increasing importance of leveraging intelligent machinery to provide precise regulation and supervision of dance movements, particularly in scenarios where human guidance is unavailable.

In the backdrop of a rapidly evolving society, the field of dance motion detection has seen a surge in research interest. Recognizing the crucial role of subtle, momentary cues in synchronized movements, recent studies have delved into exploring multifaceted dimensions of dance. For instance, Skoe et al. [1] have investigated the nuanced objectives of worldly dance, shedding light on the intricate connection between dance cognition and auditory perception. Thornquist [2] has explored the potential of dance exercise therapy as a means to reduce individuals' reliance on self-expressive substances. Additionally, research methodologies have emerged to assess the efficacy of diverse dance modalities. Reddy and Pereira [3] have proposed a compelling link between performers' and audiences' inner experiences, suggesting the possibility of generating non-local interactions through dance. Sun et al. [4] have introduced a pioneering dance self-learning framework grounded in Laban Movement Analysis (LMA) principles, enabling trainees to autonomously analyze and refine their. However, the algorithm for dance motion detection can be described in combination with sensors and human bones. Shiratori et al. [5] investigated motion structure detection by use of musical information and classified them as primitive motions. Chang et al. [6] employed the Feature Interaction Augmented Sparse Learning algorithm for motion detection based on three public Kinect-based entertainment.

Computer vision has become increasingly important and effective in recent years due to its wide application in many fields. Barbu et al. [7] proposed a new efficient learning scheme that tightens the sparsity constraint by gradually removing variables based on criteria and schedules. His experiments on real and synthetic data showed that the proposed method outperformed other state-of-the-art methods in regression, classification, and ranking while being computationally efficient and scalable and providing a foundation for dance motion detection. Cha et al. [8] proposed a damage detection method by integrating nonlinear recursive filters and non-contact computer vision-based algorithms to measure structural dynamic responses. His experimental results showed that the prediction of stiffness and damping characteristics was reasonable and accurate compared with dynamic analysis calculations, which gave a new idea for dance motion detection. Khan et al. [9] described and discussed case studies on applying Convolutional Neural Networks (CNN) in computer vision, including image classification, object detection, and semantic segmentation. The case study provides more contrastive content for dance motion detection algorithms. Fang et al.[10] developed an automatic computer vision-based method that uses two CNN models to determine whether a worker is wearing a seat belt while working at heights, which plays a good role in promoting a dance motion detection algorithm. However, these algorithms do not consider the complex factors affecting reality, so the algorithm's performance needs to be improved. In another study, Cha et al. [11] proposed a CNN architecture for diagnosing the weaknesses of concrete cracks with no fault detection extraction. Roberts et al. [12] employed the CNN for the classification of cranes to monitor the safety dangers with

utilizing UAVs (Unmanned Aerial Vehicles). Ding et al. [13] recommended an integrated learning model that employs the CNN and long-short-term memory (LSTM) combination to examine the unsafe treatment of the workers. Lecun et al. [14] investigated a combination of CNN and the Mixed National Institute of Standards and Technology (MNIST) for handwritten number detection.

Aiming at the problem of the regulation and supervision of dance movements when performing independent dance exercises without human guidance, this paper used the Kinect method to detect dance movements. Through gesture recognition, key point feature processing, and action classification, a human pose estimation algorithm was established, and motion recognition was performed. The innovation of this paper is that a set of dance assistant training systems based on Kinect is constructed based on Kinect. The system is able to receive and identify trainers' dance steps automatically. Standard moves are not compared in the database and evaluated regarding joint point coordinates and angles, so corresponding operation comparison charts and guidance can be provided.

In the presented paper, a comprehensive methodology is presented in Section II. The experimental procedure to train the dance according to Kinect in conjunction with a discussion on the obtained data is presented in Section III. Eventually, a brief conclusion is brought out about the conducted study.

## II. METHODS OF HUMAN POSE RECOGNITION

### A. Computer Vision

Humans obtain information through hearing, vision, taste, touch, and other senses, among which vision is the most important source of information. Therefore, replacing human eyes with computers for observation has become a hot topic. The perceptron of a computer is generally composed of different image sensors and electronic images. It functions like the human brain, which collects, transmits, stores, and processes image information. Computer vision technology aims to enable computers to observe the outside world independently, recognize the specific information it contains, and adapt to the environment. It can observe and understand the world like a human instead of using the eyes to do specific work. In computer vision technology, acquiring and understanding static objects is relatively easy. However, for the human body, the activities of the body are more dynamic, so it is very meaningful to capture and analyze the action posture of the human body [15], [16].

Dance training is complex and multifaceted, while basic training cultivates basic skills. The purpose of the training is to exercise the strength of each part of the trainer's body and the extensibility of the joints so that the trainer can better control his body when performing actions such as jumping, rotating, and kicking, thereby achieving better results [17], [18]. Based on retaining the original dance form has become a difficult problem in the current dance teaching to achieve accurate and graceful movements.

Kinect was originally used in games and has been used in other ways, as shown in Fig. 1. Since Kinect has open source

code, low prices, rich imaging, and powerful performance, many scholars have combined the Kinect platform to develop many different applications while developing somatosensory games [19].

Kinect can get profundity pictures of the human body through profundity distance. Kinect's imaging guideline depends on optical coding. Its functioning standard is displayed in Fig. 2. The laser shoots the laser light on the article, which the crooked medium dissipates. The laser produces a dot, which is projected on the item. Then, the spot is caught by the sensor. Because of the arbitrariness of the spot, it is important to utilize likelihood and factual techniques to break down the dot's differentiation, force dispersion, and development laws. The dissemination of laser spots is likewise arbitrary and has specific factual regulations [20], [21].

In order to solve the problem of frame rate, the theoretical frame rate of the Kinect sensor is 30 frames per second, and the depth map of each frame can reflect the true depth of a person. The depth image taken after a period can record the next person's real-time location [22]. Kinect can identify and track human bones. First, 25 key spots of the body are identified. Then, the body's skeletal structure is constructed and combined with depth information to form a three-dimensional human skeleton. The skeleton joint point model is shown in Fig. 3.

In order to identify the human body and track the bones of the target, it is first necessary to perform a deep scan on it to obtain the corresponding bone point information, which is then converted into a complete human body model. The color image is a two-dimensional image coordinate system (X, Y), and the depth image is a three-dimensional coordinate system. In the human skeleton coordinate system, (X, Y, and Z) are used as the coordinates. Bone tracking technology separates the background from the human body. Methods such as matrix transformation and machine learning are used to identify the key parts and three-dimensional coordinates of human skeletons combined with depth data, which provides convenience for future research [23]. Fig. 4 shows the skeleton tracking process of Kinect.
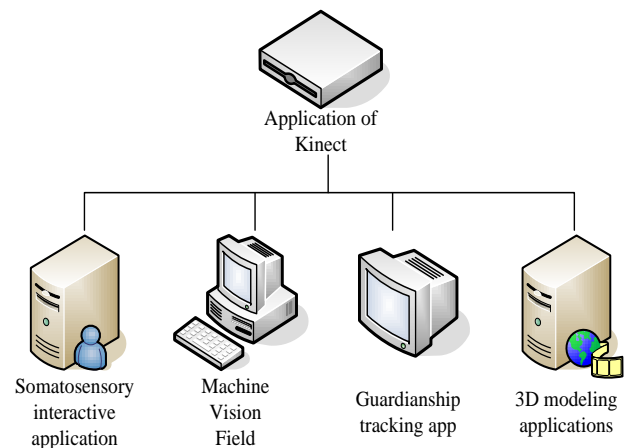


Fig. 1. Application of Kinect.
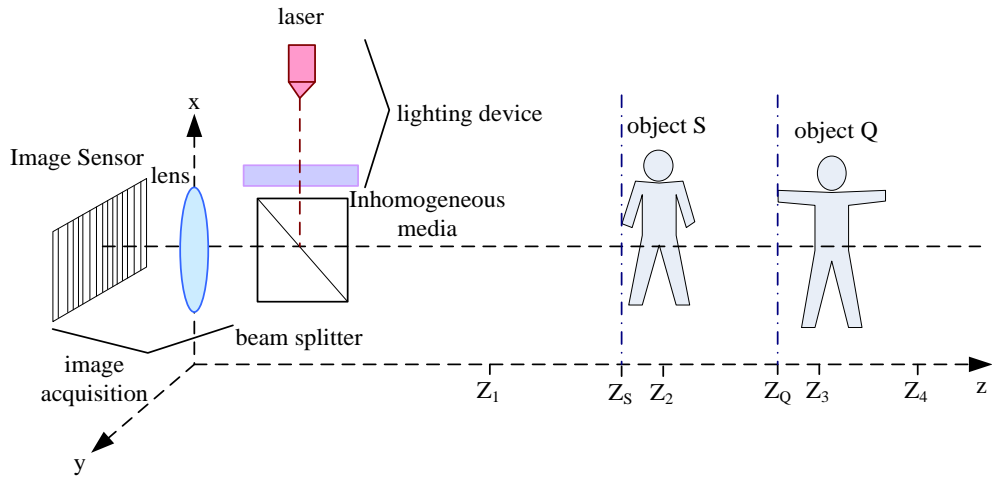
Fig. 2.   Depth imaging system.
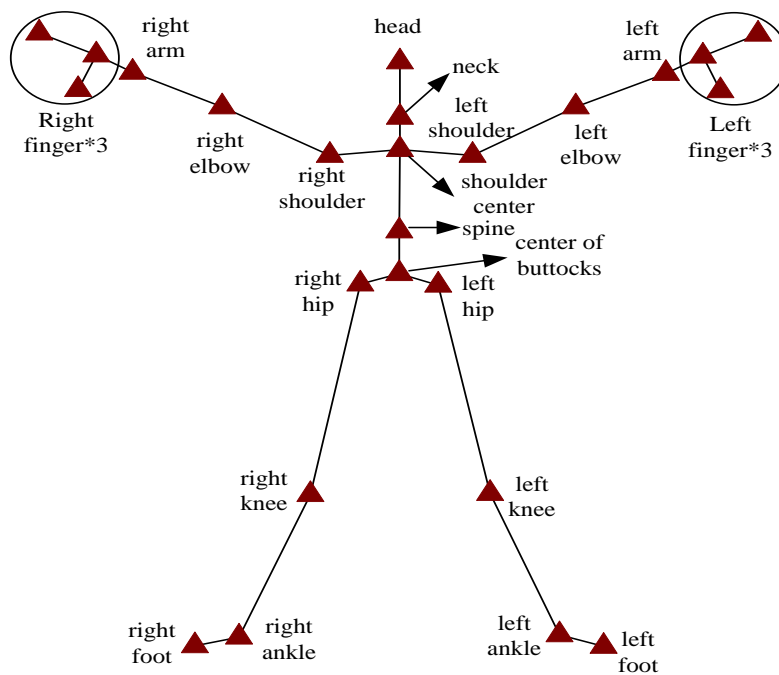


Fig. 3.   Human skeleton joint spot figure identified by Kinect.
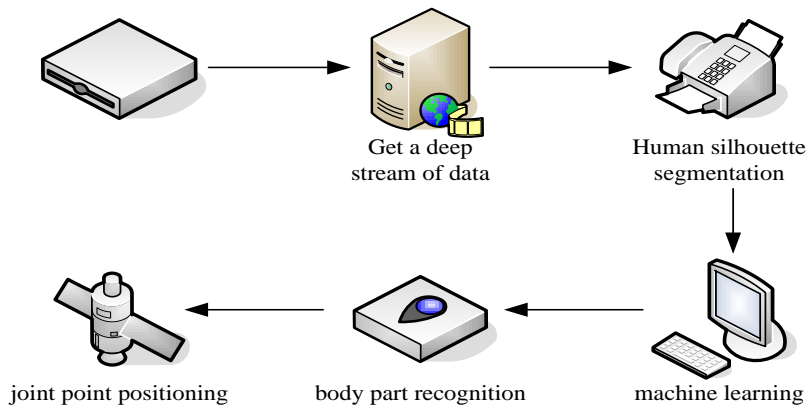


Fig. 4.   Specific steps of Kinect bone tracking.
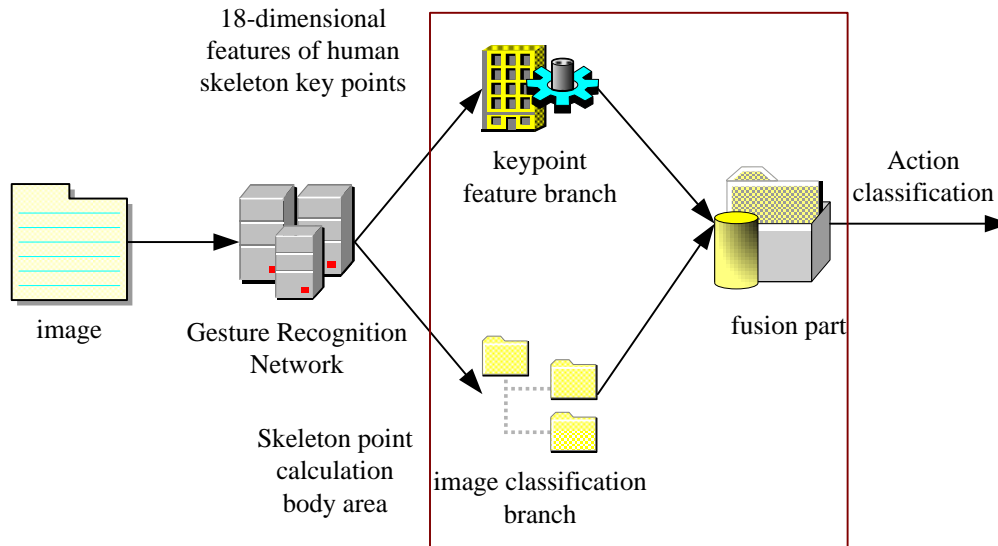
Fig. 5.  Dance action detection based on gesture recognition.

The per-pixel information can be obtained through body part recognition inference, which defines a density estimate for the body part as follows:

$$f_v(\hat{c}) \propto \sum_{o=1}^{M} e_{ov}\, exp\left(-\left\|\frac{\hat{c}-\hat{c}_o}{q_v}\right\|^2\right) \quad (1)$$

Through Formula (1), the coordinate $\hat{c}$ in a three-dimensional space is obtained. $M$ is the number of pixels and $e_{ov}$ is the weight of the pixels. $\hat{c}_o$ Represents the projection of pixel $\hat{c}$. $q_v$ represents the width of each component. $e_{ov}$ is balanced between pixel inference and the probability of spatial regions.

$$e_{ov} = A(v|O, c_o) \cdot h_z(c_o)^2 \quad (2)$$

This approach improves joint prediction accuracy while guaranteeing a constant density estimate for depth.

This paper introduces a gesture-based action recognition method. First, the image is divided into a posé recognition network with a size of 368*368. The residual network recognizes the key spots of the body. Combining the feature classification of key points and image classification, the classification of the human body can be completed, and the classification of dance movements can be achieved. The specific process of dance action detection based on gesture recognition is shown in Fig. 5.

### B. Establishment of the Human Skeleton Model

In attitude estimation, when using computer vision for attitude estimation, the first thing to solve is how to detect the human body, that is, the detection of moving objects. The recognition of moving objects is the premise of pose estimation and action recognition, and it is also the basis of skeleton tracking technology in pose estimation. The detection of moving objects is a method of using the flow information of light, or according to the difference between frames, to find the moving points of moving objects to realize the extraction of moving objects [24]. The algorithm is the first step in the human body's pose estimation and poses recognition. The moving objects are extracted to remove redundant background information, which is only analyzed for moving objects to achieve better results and accuracy.

Because the data acquisition in Kinect is 30 frames per second, the movement of the human skeleton can be regarded as an accelerated linear movement. L's the number of frames, that is, discrete moments. Then, $x_o(l)$ can represent the position of the joint point o in the X-axis direction at time $l\Delta u$. $\dot{x}_o(l)$ Is the speed of the joint point o in the X-axis direction at time $l\Delta u$. If any point in the body is defined as o, then the Taylor expansion of the formula for the position and velocity of the articulation point on the x-axis is as follows:

$$x_o(l) = x_o(l-1) + \dot{x}_o(l-1)\Delta u + \frac{\Delta u^2}{2!}\ddot{x}_o(l-1)+... \quad (3)$$

$$\dot{x}_o(l) = \dot{x}_o(l-1) + \ddot{x}_o(l-1)\Delta u + \frac{\Delta u^2}{2!}\dddot{x}_o(l-1)+... \quad (4)$$

Similarly, in the Y-axis and Z-axis directions, the position and velocity can be expanded by Taylor. Then, according to Formula (3) and Formula (4), the mathematical model is filtered:

$$x_o(l+1) = SX_o(l) + E(l) \quad (5)$$

Among them:

$$x_o(l+1) =$$

$$\begin{vmatrix} x_o(l+1) \\ \dot{x}_o(l+1) \\ y_o(l+1) \\ \dot{y}_o(l+1) \\ z_o(l+1) \\ \dot{z}_o(l+1) \end{vmatrix} \quad S = \begin{vmatrix} 1 & \Delta u & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & \Delta u & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & \Delta u \\ 0 & 0 & 0 & 0 & 0 & 1 \end{vmatrix} \quad (6)$$

$$E(l) = \left[e_{x_o}(l) \quad e_{\dot{x}_o}(l) \quad e_{y_o}(l) \quad e_{\dot{y}_o}(l) \quad e_{z_o}(l) \quad e_{\ddot{z}_o}(l)\right]^U \quad (7)$$

S is the state transfer matrix of the system. It estimates the movement of skeletal points through the $W(l)$ -diagonal matrix method and the process noise covariance matrix $E(l)$.

The following is the mathematical model for the observation matrix :

$$Z_o(l) = JX_o(l) + B(l) \qquad (8)$$

Among them:

$$Z_o(l) = \begin{vmatrix} x_o^n(l) \\ y_o^n(l) \\ z_o^n(l) \end{vmatrix} \cdot J \begin{vmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \end{vmatrix}, B(l) \begin{vmatrix} b_x(l) \\ b_y(l) \\ b_z(l) \end{vmatrix} \qquad (9)$$

The observed variable is $Z \in T^n$. J is the measurement matrix. $T(l)$ is used as the covariance matrix of measurement noise $B(l)$.

The above Formulas (5) and (8) are the mathematical model and observation model of the state matrix in the three-dimensional coordinate system of the joint points of the human body. Among them, the joint point models are the position and velocity components under the X, Y, and Z axes. $X_o(l)$, $E(l)$, $Z_o(l)$, $B(l)$, etc. are the results in six dimensions. In the actual solution, the X, Y, and Z axes are independent and similar to each other, which can be calculated under the X, Y, and Z axes, respectively, by using the dimensionality reduction method. Then, the estimated value of the current skeleton point in the x dimension is as follows:

$$x_o(l) = \begin{bmatrix} x_o(l) \\ \dot{x}_o(l) \end{bmatrix} = \begin{bmatrix} 1 & \Delta u \\ 0 & 1 \end{bmatrix} \begin{bmatrix} x_o(l-1) \\ \dot{x}_o(l-1) \end{bmatrix} + \begin{bmatrix} e_{x_o}(l) \\ e_{\dot{x}_o}(l) \end{bmatrix} \qquad (10)$$

$$z_o(l) = \begin{bmatrix} 1 & 0 \end{bmatrix} \begin{bmatrix} x_o(l) \\ \dot{x}_o(l) \end{bmatrix} + b_o(l) \qquad (11)$$

With extensive data collection, $S = \begin{bmatrix} 1 & \Delta u \\ 0 & 1 \end{bmatrix}$, $J = \begin{bmatrix} 1 & 0 \end{bmatrix}$, $W(l)$ and $T(l)$ can be derived. Through multiple data acquisition and calculation, $W(l)$ is a diagonal matrix with a value of 0.25 on the diagonal. $T(l)$ Is a diagonal matrix with values three on the diagonal. Then, the Kalman gain matrix $L_l$ of the intermediate operation is derived from this formula. The estimated position of the skeletal joint point o in l frame time is obtained.

*C. Trainer Gesture Recognition*

In dance training, a trainer's posture assessment is an important factor in measuring the standard of his movements. The images produced by Kinect contain dance trainers and training scenes. Therefore, the target is extracted from the training object. In this paper, the inter-frame difference method is used to extract the moving objects of athletic dance trainers.

When using the inter-frame difference method to extract the moving target of the athletic dance trainer, it is necessary to compare the two frames of images and set the threshold. If the difference between two adjacent images is less than a threshold, the content of this image is a training scene, not a training object. If the difference between two adjacent images is greater than a threshold, then the content of this image is the trained object. This program can be expressed as:

$$Q(x,y) = |O_{l+1}(x,y) - O_l(x,y)| \qquad (12)$$

$$F(x,y) = \begin{cases} 0, Q(x,y) < U \\ 255, Q(x,y) \geq U \end{cases} \qquad (13)$$

In the formula, $Q(x,y)$ is the difference image of $O_{l+1}(x,y)$ and $O_l(x,y)$ for two adjacent two frames. $F(x,y)$ To $Q(x,y)$ binarized image. U is the set threshold.

After identifying the training object, feature extraction is performed. In this paper, the Canny algorithm is used to extract the features of the training objects. The Canny algorithm detects the boundaries of the objects being trained. Then, feature extraction is performed by connecting edges. When Canny's algorithm extracts features, it must smooth them:

$$G(x,y) = \frac{1}{2\pi\delta^2} exp\left(-\frac{x^2+y^2}{2\delta^2}\right) \qquad (14)$$

Next, in the image $(x,y)$, the gradient magnitude $Z(x,y)$ and the direction $f(x,y)$ on the pixel point are found :

$$Z(x,y) = \sqrt{a_x^2(x,y) + a_y^2(x,y)} \qquad (15)$$

$$f(x,y) = arv\, tan\left(\frac{a_x(x,y)}{a_y(x,y)}\right) \qquad (16)$$

Then, the non-maximum denoising of gradient magnitude $Z(x,y)$ and direction $f(x,y)$ are used to get candidate edges. An edge point extraction method based on the double-threshold method is proposed and stitched to realize the feature extraction of images.

In response to this situation, a gradient direction-based suppression algorithm is proposed, which is used to extract and connect candidate edge points.

By detecting human body points, the location of the human body can be realized through the point information in the sample library. This paper uses the Euclidean distance method to perform the matching operation between nodes. The specific steps are as follows:

$$J = \sqrt{(x_1, x_2)^2 + (y_1, y_2)^2} \qquad (17)$$

In the formula, J is used to represent the corresponding pose, and the node coordinates and joint point coordinates detected in the sample library are $(x_1, x_2)$ and $(y_1, y_2)$.

Using the above steps, the body poses estimation of the sports dance trainer is completed.

## III. EXPERIMENT OF DANCE-ASSISTED TRAINING BASED ON KINECT

In light of Kinect, this paper fosters a dance partner preparing framework in view of Kinect. This paper utilizes Kinect innovation to gather standard movement information for a PC. A data set of standard dance acts is made and utilized format. The mentor's development information and the layout pose are contrasted to understand the assessment of the learner's development pose, which brings the digitalization of dance preparation into another stage.

Ballet is the most logical and standard dance. It focuses on the accuracy of the developments and communicates the artists' feelings and contemplations with exclusive requirement dance steps. Expressive dance essential preparation is an expert, standard, and logical dance education. To this end, this article treats fundamental artful dance preparation as a trial dance-helped workout.

## A. System Design

The centre substance of the framework incorporates information securing, handling, and examination. On this premise, the movement boundaries are investigated. A set of standard dance developments is built using the mentor's development data. The information handling is, for the most part, to fix the impeded joints and re-establish them. Information examination is to think about the development data between the mentor and the standard developments. The related preparation plan is acquired in order to work on the capacity of the mentor rapidly. The engineering of the framework is displayed in Fig. 6.

Hardware for this article includes Kinect for Microsoft Windows 2.0 and a PC with Windows 8. The Kinect is connected to the computer using a USB interface. Kinect is used to acquire 2D, deep images of the human body, which are also analyzed and processed.

In terms of software, it mainly includes capturing the action and analyzing action information. The motion information collection part mainly completes the collection of two-dimensional images of the human body, skeletal nodes, and depth. The movement information analysis compares the couch's motion information with the corresponding data in the confirmed dance motion database. The key point is to compare each link's positions and joint angles. Fig. 7 shows the operation interface design of the system.

## B. Data Collection

To justify the dance steps of the students, it is necessary to have a standard dance step for comparison. This part uses the trainer's action extraction and the occlusion point information to restore and obtain the standard motion data.

This article maps each data label to an action name. It is stored uniformly as exercise information for training personnel to compare. There is a whole of 30 sets of primary instructing moves in the info archive. Every group is divided into four decomposing movements, with a total of 120 movements, which meets the basic requirements of the students.

Using Kinect technology, data collection of ballet hand positions is carried out. The trainer performs a series of dance steps before the Kinect. Kinect can capture the trainer's dance in real time and correct it through the occlusion point to obtain the trainer's physical condition. Finally, the training results are compared with the standard motion data.
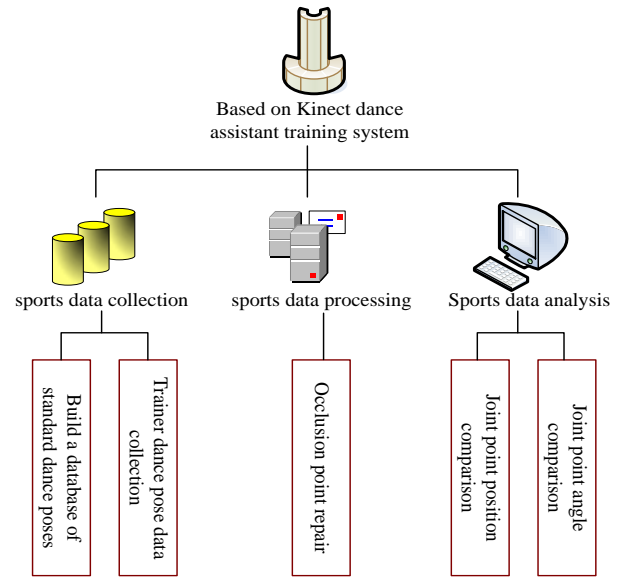


Fig. 6. Block diagram of the Kinect-based dance assistant training system.
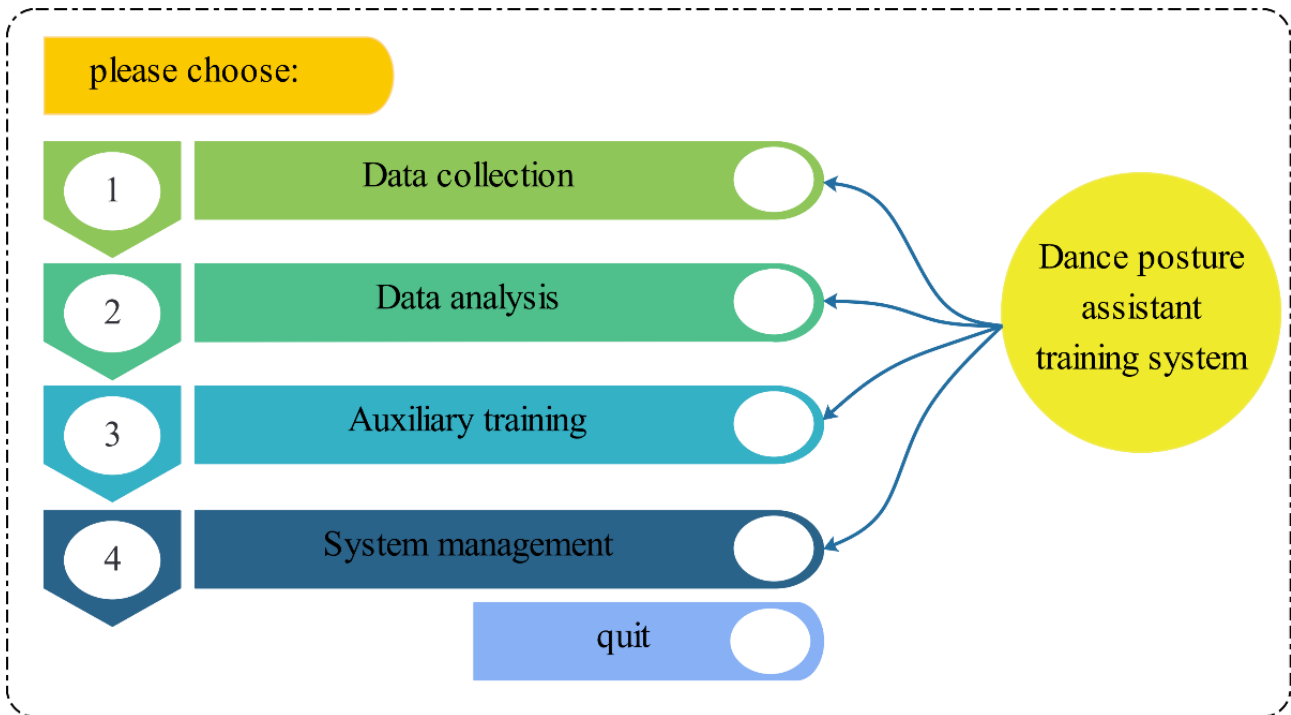


Fig. 7. Design of the software interface of the auxiliary training system.

*C. Dance Auxiliary Training*

This section of dance-assisted training mainly analyzes the trainer's key parts and the joints' angles. The auxiliary training system (see Tables I and II) collects each trainee's movement key point coordinates, which are compared with the standard movements of the choreographer (see Table III). By comparing the movement trajectories of various points, it is easy to find the dissimilarity between the couch's move and the approved move.

TABLE I.        COUCH 1 ACTION JOINT COORDINATES

| Part | Standard dance joint point coordinates | |
| --- | --- | --- |
| | *Abscissa* | *Y-axis* |
| head | -79.2 | 217.1 |
| Neck | -24.6 | 31.7 |
| left shoulder | -149.9 | -49.1 |
| left elbow | -376.1 | -51.8 |
| left hand | -652.9 | -60.2 |
| Right hand | 96.5 | -7.4 |
| Right elbow | 81.4 | 222.7 |
| Right shoulder | 48.0 | 508.4 |
| Right knee | -106.4 | -864.6 |
| Right foot | -67.0 | -1158.7 |
| left knee | -236.7 | -936.7 |
| left foot | -312.5 | -1169.7 |

TABLE II.        TRAINER 2 JOINTS ACTION COORDINATES

| Part | Standard joint dance spot coordinates | |
| --- | --- | --- |
| | *Abscissa* | *Y-axis* |
| head | -81.4 | 217.2 |
| Neck | -26.6 | 31.0 |
| left shoulder | -151.5 | -51.3 |
| left elbow | -376.1 | -53.6 |
| left hand | -652.8 | -62.5 |
| Right hand | 96.8 | -9.6 |
| Right elbow | 80.9 | 222.7 |
| Right shoulder | 47.4 | 508.1 |
| Right knee | -108.0 | -866.4 |
| Right foot | -68.8 | -1160.2 |
| left knee | -238.5 | -938.4 |
| left foot | -314.6 | -1172.0 |

TABLE III.        STANDARD ACTION JOINT COORDINATES

| Part | The trainer's joint spot coordinates | |
| --- | --- | --- |
| | *Abscissa* | *Y-axis* |
| head | -68.5 | 269.9 |
| Neck | -68.5 | 74.9 |
| left shoulder | -208.7 | -2.4 |
| left elbow | -407.7 | -108.5 |
| left hand | -634.8 | -180.2 |
| Right hand | 309.9 | 373.1 |
| Right elbow | 237.0 | 153.2 |
| Right shoulder | 91.2 | 1.6 |
| Right knee | -127.4 | -828.1 |
| Right foot | -161.0 | -994.5 |
| left knee | -23.6 | -856.9 |
| left foot | -12.4 | -1000.3 |

It can be seen from Table I, Table II, and Table III that the height of the trainer's arm raises to the highest point does not meet the requirements. The difference between the data of Trainer 1 and Trainer 2 is not particularly large, which is within a certain range. It can be seen that the abscissa of the coordinates of the two trainers is slightly different from the abscissa of the standard dance joint point. The standard abscissa is -12.4. Trainer 1 is -312.5, and Trainer 2 is -314.6, which is over 300 errors. The comparison of Fig. 8 can be drawn from the above data. As can be seen from the graphs in Fig. 8(a) and 8(b), the trainer's wrist should be raised by approximately 200 mm. Moreover, the speed of closing the hand is too fast, which does not meet the standard action.
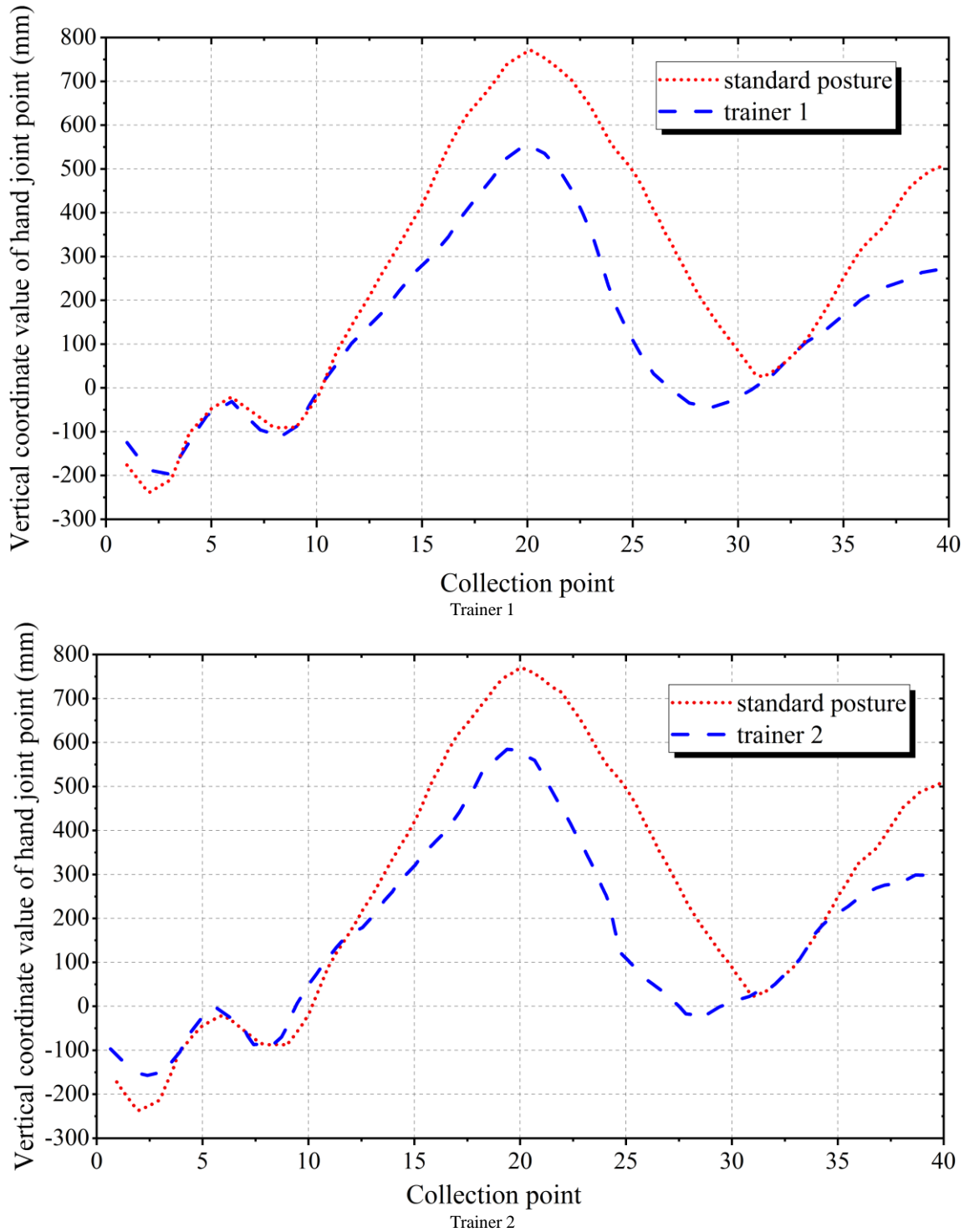


Trainer 1



Trainer 2

Fig. 8. Comparison of the movement trajectories of the two trainers and the standard movement trajectories.

On this basis, three hand movements in dance are analyzed. The included angle of each joint in this action is obtained. It can be seen that there is a certain difference between the movements of the trainer and the standard movements. Teachers of different ranks would be able to carry out aimed teaching based on their own abilities. Fig. 9 shows the disparity of the joint angles between the trainer and the standard movement. Fig. 9(a), (b), and (c) are the comparisons between Action 1, Action 2, and Action 3, respectively.

The following description is made with reference to operation 1 (operation at five positions) of Fig. 9(a). As can be seen from the figure, the angle between the trainer's right wrist-right elbow-right shoulder is rather big. The included angle of the waist-right knee-right ankle is also rather big. Therefore, the next time the trainer exercises, the five elbows and right arms should be straightened. At the same time, the trainer should lean the waist slightly forward and bend the right leg. The angle between the neck-right shoulder-right elbow is too big, and the angle between the left wrist-left elbow-left shoulder is relatively tiny. Therefore, in the next exercise, the trainer should try to reduce the curvature of the left elbow and left wrist as much as possible.



(a) Action 1

(b) Action 2

(c) Action 3
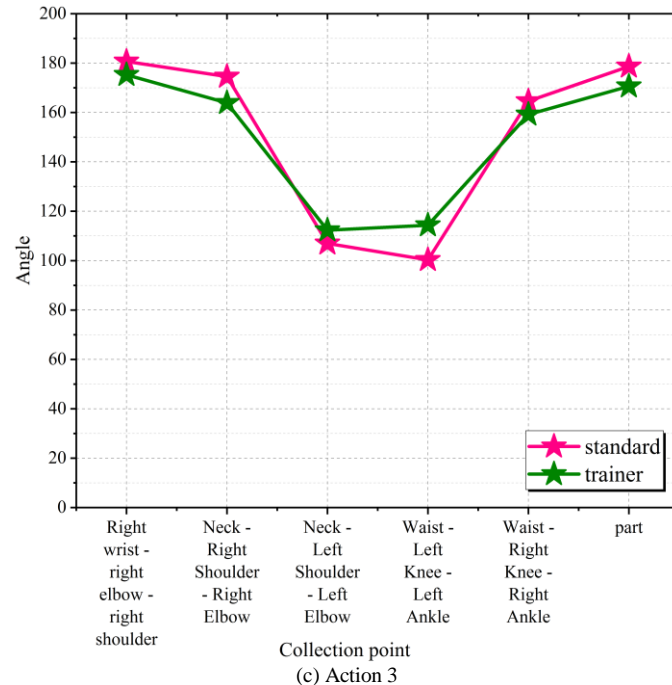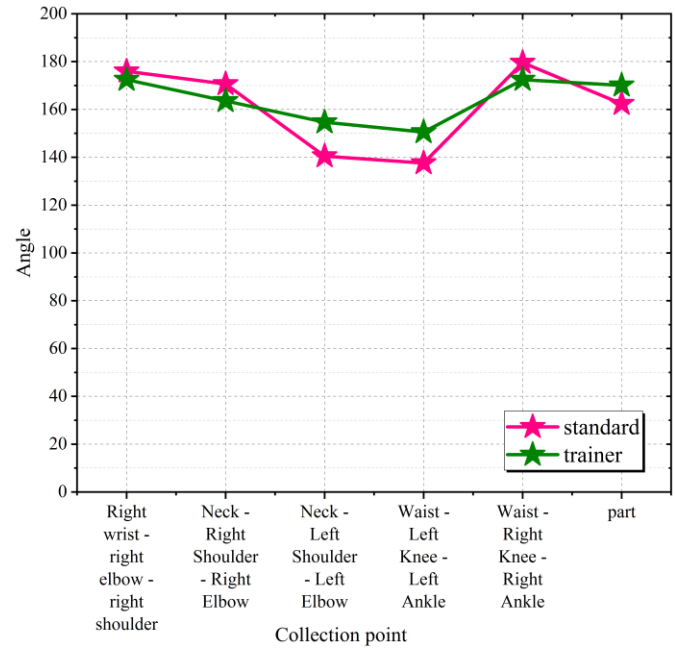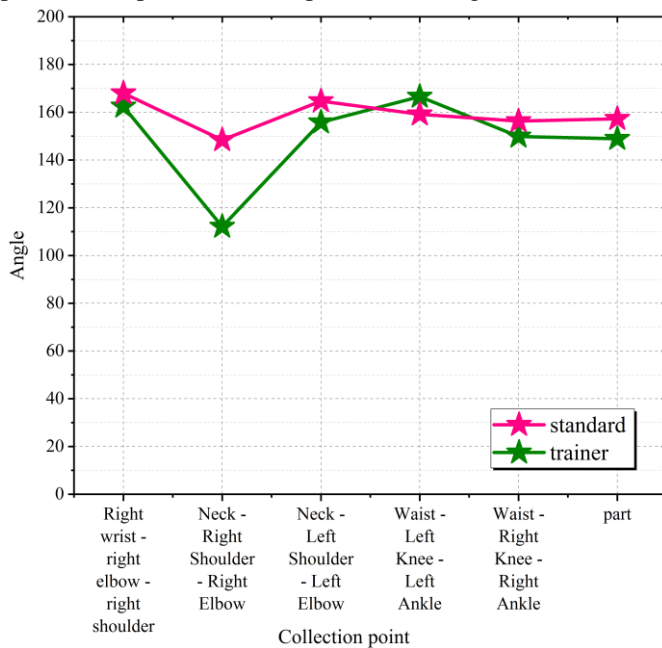
Fig. 9. Comparison of the joint angles of the trainer and the standard movement.

(a) Trainer's five-position hand movement

(b) Standard five-position hand movement
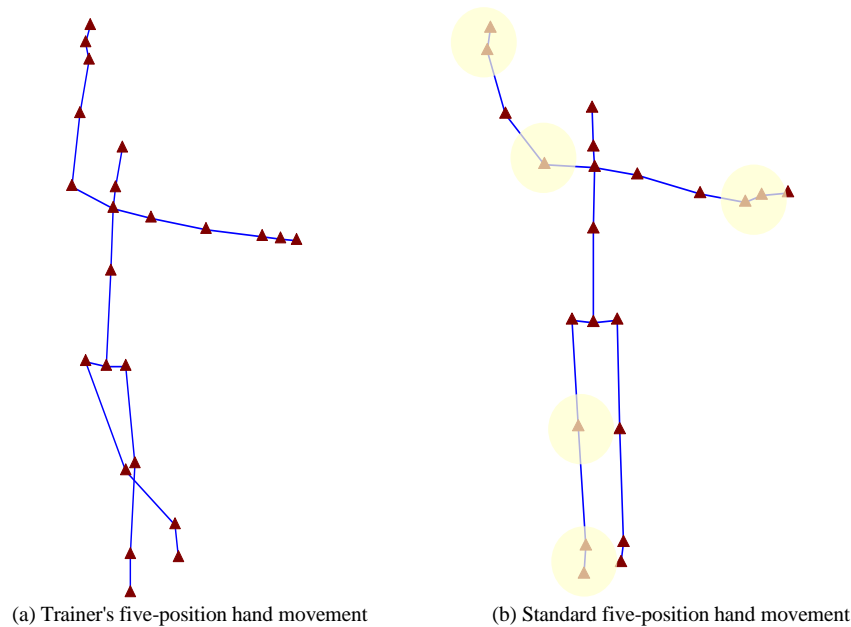
Fig. 10. Comparison of the five-hand movements of the trainer and the standard five-hand movements.

In order to more intuitively compare the movements of the trainer and the dance instructor, the system shows the dissimilarity between the teacher's and the approved moves, as shown in Fig. 10. Fig. 10(a) is the operation of five hand exercise trainers. Fig. 10(b) is a standard five-hand exercise.

The equipment and programming portions of the framework are talked about exhaustively above as far as information assortment and standard dance moves are placed into the framework. A standard human dance present data set is built. The information handling part fixes the covered key parts and re-establishes the skeleton of the human body. Assistant preparation incorporates joint point situating and joint point-based helper preparation. The artist's dance act is examined by the directions of the endpoint and the point framed by the joints. The framework can acquire the related preparing program through correlation, which empowers understudies to make fitting changes as indicated by the prompts of the product in order to accomplish the impact of helper preparing.

## IV. Conclusion

In this study, we leveraged the capabilities of the Kinect3D sensor and harnessed its skeletal tracking technology to capture comprehensive dance movements and training data. These data were meticulously compared to standard movements, providing users with a valuable tool to discern the nuances of their own performance. This innovative approach has far-reaching implications for dance instructors, professional dancers, and dance enthusiasts seeking to refine their skills through dedicated training and self-education.

The primary achievement of our work lies in its capacity to empower individuals to make precise adjustments to their dance postures, thereby ensuring the utmost accuracy in their dance practice. A significant advantage of this method is the liberation from the constraints of geographical location, time limitations, and spatial boundaries. Dancers can now engage in training sessions at their convenience, transcending traditional barriers. This expanded accessibility to training opportunities enhances the versatility and adaptability of our dance motion detection algorithm.

Furthermore, our system offers an interactive experience that not only facilitates correct posture adjustments but also cultivates a sense of rhythm among users through computer-assisted feedback. By embracing digitalization and informatization, we contribute to the ongoing modernization of dance training methods.

In conclusion, our work demonstrates the potential of computer vision and Kinect technology to revolutionize dance training. The ability to receive real-time feedback and guidance, combined with the freedom of practice, opens new avenues for dancers to hone their skills. However, it is essential to acknowledge that our approach does have limitations, including [mention limitations here], and we envision several exciting directions for future research. As we continue to explore these frontiers, we anticipate further advancements in the field of dance motion detection and its application in enhancing dance education and practice.

## Data Availability

Data is available in our manuscript.

## Conflicts of Interest

We confirm there are no potential competing interests in our manuscript.

## References

[1]   E. Skoe, E. V Scarpati, and A. McVeety, "Auditory temporal processing in dancers," *Percept Mot Skills*, vol. 128, no. 4, pp. 1337–1353, 2021.

[2]   C. Thornquist, "The potential of dance: Reducing fashion consumption through movement therapy," *J Clean Prod*, vol. 183, pp. 824–830, 2018.

[3] J. S. K. Reddy and C. Pereira, "From expressions to ecstasy: understanding the phenomenon of experiential interaction between the performer and audience in dance," *Dance, Movement & Spiritualities*, vol. 5, no. 1, pp. 89–99, 2018.

[4] G. Sun, W. Chen, H. Li, Q. Sun, M. Kyan, and P. Zhang, "A Virtual Reality Dance Self-learning Framework using Laban Movement Analysis.," *Journal of Engineering Science & Technology Review*, vol. 10, no. 5, 2017.

[5] T. Shiratori, A. Nakazawa, and K. Ikeuchi, "Detecting dance motion structure through music analysis," in *Sixth IEEE International Conference on Automatic Face and Gesture Recognition, 2004. Proceedings.*, 2004, pp. 857–862. doi: 10.1109/AFGR.2004.1301641.

[6] X. Chang, Z. Ma, M. Lin, Y. Yang, and A. G. Hauptmann, "Feature Interaction Augmented Sparse Learning for Fast Kinect Motion Detection," *IEEE Transactions on Image Processing*, vol. 26, no. 8, pp. 3911–3920, 2017, doi: 10.1109/TIP.2017.2708506.

[7] A. Barbu, Y. She, L. Ding, and G. Gramajo, "Feature selection with annealing for computer vision and big data learning," *IEEE Trans Pattern Anal Mach Intell*, vol. 39, no. 2, pp. 272–286, 2016.

[8] Y.-J. Cha, J. G. Chen, and O. Büyüköztürk, "Output-only computer vision based damage detection using phase-based optical flow and unscented Kalman filters," *Eng Struct*, vol. 132, pp. 300–313, 2017.

[9] S. Khan, H. Rahmani, S. A. A. Shah, M. Bennamoun, G. Medioni, and S. Dickinson, *A guide to convolutional neural networks for computer vision*, vol. 8, no. 1. Springer, 2018.

[10] W. Fang, L. Ding, H. Luo, and P. E. D. Love, "Falls from heights: A computer vision-based approach for safety harness detection," *Autom Constr*, vol. 91, pp. 53–61, 2018.

[11] Y.-J. Cha, W. Choi, and O. Büyüköztürk, "Deep Learning-Based Crack Damage Detection Using Convolutional Neural Networks," *Computer-Aided Civil and Infrastructure Engineering*, vol. 32, no. 5, pp. 361–378, May 2017, doi: 10.1111/mice.12263.

[12] D. Roberts, T. Bretl, and M. Golparvar-Fard, "Detecting and Classifying Cranes Using Camera-Equipped UAVs for Monitoring Crane-Related Safety Hazards," in *Computing in Civil Engineering 2017*, pp. 442–449. doi: 10.1061/9780784480847.055.

[13] L. Ding, W. Fang, H. Luo, P. E. D. Love, B. Zhong, and X. Ouyang, "A deep hybrid learning model to detect unsafe behavior: Integrating convolution neural networks and long short-term memory," *Autom Constr*, vol. 86, pp. 118–124, Feb. 2018, doi: 10.1016/j.autcon.2017.11.002.

[14] Y. Lecun, L. Bottou, Y. Bengio, and P. Haffner, "Gradient-based learning applied to document recognition," *Proceedings of the IEEE*, vol. 86, no. 11, pp. 2278–2324, 1998, doi: 10.1109/5.726791.

[15] P. Pareek and A. Thakkar, "A survey on video-based human action recognition: recent updates, datasets, challenges, and applications," *Artif Intell Rev*, vol. 54, pp. 2259–2322, 2021.

[16] A. Dixit, R. Kumar Chidambaram, and Z. Allam, "Safety and risk analysis of autonomous vehicles using computer vision and neural networks," *Vehicles*, vol. 3, no. 3, pp. 595–617, 2021.

[17] A. Sööt and E. Viskus, "Contemporary approaches to dance pedagogy–The challenges of the 21st century," *Procedia-Social and Behavioral Sciences*, vol. 112, pp. 290–299, 2014.

[18] J. Jin and B. Snook, "Comprehensively strengthening and improving aesthetic education in a new era: An examination of the dance education major at the Beijing dance academy," *International Journal of Chinese Education*, vol. 11, no. 3, p. 2212585X221127451, 2022.

[19] L. Wang, D. Q. Huynh, and P. Koniusz, "A comparative review of recent kinect-based action recognition algorithms," *IEEE Transactions on Image Processing*, vol. 29, pp. 15–28, 2019.

[20] Y.-F. Xiao, H. Huang, J. Zheng, and L. Ran, "Obstacle detection for robot based on kinect and 2d lidar," *Journal of University of Electronic Science & Technology of China*, vol. 47, no. 3, pp. 337–342, 2018.

[21] H. Liu, C. Pan, Y. Shen, and B. Gao, "Plant Point Cloud Information Fusion Method Based on SICK and Kinect Sensors," *Trans. Chin. Soc. Agric. Mach*, vol. 49, no. 10, pp. 284–291, 2018.

[22] Y. Sun *et al.*, "Retracted: Gesture recognition algorithm based on multi-scale feature fusion in RGB-D images," *IET Image Process*, vol. 14, no. 15, pp. 3662–3668, 2020.

[23] Y. Z. Xin and Z. F. Xing, "Human action recognition method based on Kinect," *Computer Engineering & Design*, vol. 37, no. 4, pp. 1056–1061, 2016.

[24] X. Wang, J. Liu, and Q. Zhou, "Real-time multi-target localization from unmanned aerial vehicles," *Sensors*, vol. 17, no. 1, p. 33, 2016.

# Seamless Data Exchange: Advancing Healthcare with Cross-Chain Interoperability in Blockchain for Electronic Health Records

Reval Prabhu Puneeth[1], Govindaswamy Parthasarathy[2]

Assistant Professor, Department of Computer Science and Engineering,
NMAM Institute of Technology - Affiliated to NITTE (Deemed to be University)[1]
Research Scholar, School of Computing and Information Technology, REVA University, Karnataka, India[1]
Professor, School of Computing and Information Technology, REVA University, Karnataka, India[2]

*Abstract*—The rapid digitization of healthcare records has led to the accumulation of vast amounts of sensitive patient data, stored across various systems and platforms. To ensure the secure and efficient exchange of Electronic Health Records (EHRs) among healthcare providers, researchers, and patients themselves, the concept of cross-chain interoperability within blockchain technology emerges as a promising solution. Nevertheless, existing blockchain platforms exhibit several limitations. In order to address the issue of non-interoperability, the suggested method involves creating a connection between two similar blockchain networks. This solution is exemplified through the use of an Electronic Health Records (EHR) structure, which is distributed across distinct Ethereum Testnets and implemented via a Solidity Smart Contract. The paper aims to demonstrate the viability of bridging the gap and fostering seamless interoperability between blockchain networks. However, establishing effective communication between these smart contracts proves to be a complex endeavor, whether within a singular blockchain or spanning multiple blockchains. This complexity presents a formidable obstacle, particularly when diverse hospitals require the sharing or exchange of critical information. Consequently, a solution becomes imperative to facilitate cross-chain communication among smart contracts. This solution provides seamless operation both within the confines of a single blockchain and across disparate blockchains. By achieving this, cross-chain interoperability can be realized, enabling distinct blockchain networks to mutually comprehend and actively engage with each other.

*Keywords—Electronic health records; data sharing scheme; blockchain technology; solidity smart contract; cross-chain interoperability*

## I. INTRODUCTION

Telecare Medicine Information System (TMIS) takes use of the dramatic improvement in telecommunications and information technologies to deliver healthcare to patients in their homes. TMIS enables doctors to collaborate and share vital information about their patients' conditions, even when they are physically separated by long distances and working from different offices. In this way, TMIS drastically reduces the price of care by making it more accessible to more people. If the most recent state of a patient's health is to be taken into account while making medical decisions, then an effective electronic-health (e-health) system is essential. However, it might be difficult for doctors to effectively diagnose and treat new patients because they lack immediate access to the patient's complete medical history and other relevant data [1]. EHRs contain information about patients, including demographics, lab results, medical scans, clinical notes, billing data, sensor data, medical history, medications, insurance details, and more; in an e-health system, these restrictions may be less of an issue. Ensuring the confidentiality, privacy, and integrity of data within this system is unquestionably crucial. Nevertheless, the specific needs of different e-health systems may vary depending on the privacy laws in place in the country where the system is located [2]. Although there is still work to be done on interoperability and privacy concerns, EHR are now widely recognized as an integral element of the healthcare business.

Many scholars have proposed confidential data-sharing strategies to meet the expanding demands of the healthcare industry. Conventional healthcare data-sharing systems, on the other hand, rely on a centralized system that does not provide a safe method of exchanging data with other medical-related organizations. However, because regulatory bodies may lack access to data held by medical institutions, there is a significant opportunity for improper exploitation of patients' medical information [3]. Consequently, in the event of resource sharing, data-sharing methods cantered around a centralized framework are not appropriate for the advancement of e-medical records.

### A. Blockchain Technology

Blockchain stands as an advanced database technique that fosters transparent data exchange across a network. It operates on the principle of organizing data into interconnected "blocks" that form an unbroken "chain." In this analogy, the blocks in the blockchain are akin to nodes in a linked list, collectively constituting the chain [4].

Within each block of the blockchain, you find data and a hash value that establishes its connection to the preceding block. A significant feature of this technology is the inherent inability to modify links or alter the chain without gaining widespread consensus. This ensures that the information remains meticulously arranged in chronological order. As a result, blockchain technology provides an immutable ledger capable of recording a diverse range of transactions.

Blockchain solves problems by generating a decentralized, unchangeable method of recording transactions. Each party in a real estate deal may have their own ledger thanks to blockchain technology. Both parties must agree to a transaction before it is finalized, and the ledgers will be updated simultaneously. If any transaction in the past is changed, the integrity of the entire ledger is compromised [5]. These features of blockchain technology have led to its use in several fields, most notably the creation of digital currencies like Bitcoin.

The privacy concerns associated with the implementation of EHRs as healthcare data increasingly moves into the digital realm. Governments globally have introduced legislation and regulations to protect personal information, yet data breaches within electronic health records continue to rise, with theft and loss being the primary causes. This underscores the critical need for stricter control and limited access to patients' private medical data [6]. The blockchain technology could offer a potential solution. It describes blockchain as a decentralized, distributed ledger system that encrypts and links data in a secure and transparent manner. Consensus algorithms ensure agreement among network nodes regarding legitimate data access, and data is only added to the blockchain after undergoing validation for accuracy and relevance [7].

Blockchain is noted for its advantages, including user autonomy, increased data sharing transparency, and heightened data privacy and security. The importance of decentralization lies in its ability to create a robust and tamper-resistant system where altering data becomes difficult without alerting other nodes in the blockchain network. Encrypting data within each block using cryptographic hashes like the SHA-256 algorithm for enhanced privacy and security. These hashes make it extremely difficult to reverse-engineer the original data from the hash value, thereby protecting the blockchain against tampering by malicious actors. Through a combination of encryption, decentralization, and consensus mechanisms, blockchain offers a promising solution for safeguarding sensitive healthcare data in the increasingly digital healthcare landscape [8].

*B. Blockchain Interoperability*

Blockchain interoperability is the ability to view, access, and share data across various blockchain networks. It emphasizes the significance of interoperability in making blockchain applications more transparent and efficient. In the healthcare context, the term "interoperability" refers to the exchange of patient data between different electronic health record systems, with challenges arising from hardware and software heterogeneities. The idea of smart contracts, which are programs that execute, predefined operations on a blockchain [9]. However, it points out limitations in the inter-network communication between smart contracts, highlighting the need for solutions to enable cross-chain communication among them [10]. The ultimate goal is to achieve cross-chain interoperability, allowing different blockchains to understand and interact with each other. The importance of addressing non-interoperability issues and suggests building a bridge between similar blockchain networks, using Electronic Health Records (EHR) as an example.

The structure of the upcoming sections in this paper is as outlined below: Section II elaborates on the prior approach to utilizing blockchain-based EHR. In Section III, the techniques proposed for this study are introduced. The advancement of the experiment, which validates the assertions of this research and includes the results, is covered in Section IV. Lastly, Section V provides the experiment's conclusions.

## II. Literature Review: Related Studies

Blockchain is a decentralized ledger that records and shares a comprehensive history of transactions and electronic events among its participants. A significant feature is that most participants validate all public transactions, ensuring the permanence and non-disputability of stored information. This addressing the vital need to safeguard and maintain sensitive patient data in a secure cloud-based environment, addressing concerns related to data creation, distribution, storage, and retrieval in the healthcare sector [11].

The solution involves using Blockchain technology to protect cloud-based medical records. By combining distributed computing with blockchain, disparate healthcare providers can establish secure connections, facilitating remote access to patient information while ensuring its confidentiality. Data undergoes encryption before uploading to the cloud, and healthcare providers must decrypt it for access. The use of cryptography during encryption ensures secure data transmission between clients and servers [12].

Personal health records (PHRs) are often stored and processed in centralized client-server architecture in conventional healthcare systems. Due to technological and infrastructure limitations, PHR kept at a healthcare facility remain in repository and cannot be easily shared with other institutions [13]. There is no efficient and confidential data exchange process in place if a patient has to see many doctors or hospitals. Health Insurance Portability and Accountability Act (HIPAA) may safeguard patients' privacy; however this is questionable because it does not take into account whether or not the patient is personally involved.

According to the author [14], studies on the use of blockchain technology to ensure confidentiality and safety in healthcare are commonplace on the distributed ledger. However, they have diverted emphasis from the distribution of the encryption/decryption key needed to ensure PHR confidentiality and instead cantered it on the maintenance of individual health records. In order to construct trustworthy and decentralized systems, blockchain offers a shared, immutable, and visible history of all transactions. This opens the door for the use of blockchain technology in the creation of a safe and reliable PHR data management system. This study introduces an approach that empowers patients by necessitating them to possess the information required to deduce the encryption /decryption key from previous transactions within blockchains. Through this key-based access restriction, patients gain control over their own medical records. If you're looking for a vibrant industry that embraces technology to provide superior care with a focus on the patient, look no further than healthcare.

Artificial intelligence (AI), the Internet of Things (IoT), and blockchain provide a diverse set of uses that may be put to good use in the healthcare industry. Potentially improving monitoring processes and decreasing clinical-related mistakes is one role that healthcare environments may play. To improve healthcare delivery, [15] presents a new architecture that integrates ambient intelligence into the healthcare infrastructure. As the foundation of the network, blockchain ensures the safekeeping and sharing of data among all of its participants. In order to collect data on vital signs, a hardware prototype is created using a Raspberry Pi Model 4B.

The high-performance computing system, integrated with machine learning algorithms and blockchain capabilities, is employed to efficiently store critical patient data and notify healthcare professionals of any discrepancies. Comparative analysis reveals that this new system surpasses existing models in terms of reliability and latency. Metrics like mean average error (MAE), mean square error (MSE), and root mean square error (RMS) are used to comprehensively evaluate algorithm performance. Notably, this system offers the seamless integration of pre-existing models and demonstrates effective functionality overall.

However, the security challenges associated with patient data storage in IT systems have hindered the progress of e-healthcare. The introduction of blockchain technology offers a potential solution, which is explored in the work outlined in reference [16]. This research establishes the foundation for blockchain-based health information management, encompassing a public ledger, private ledger, smart contracts, and context-based access control. The proposed design ensures patient data access, security, and system compatibility, while also presenting an efficient approach to managing complex medical processes. Furthermore, the report delves into the application of blockchain technology in healthcare, emphasizing its potential for confidential patient data exchange for scientific research. Smart contracts are recommended for maintaining patients' medical histories, described as innovative, accessible, interoperable, and auditable.

Prominent healthcare communication networks generate data and information, but recent years have seen these systems become targets for cyberattacks due to inadequate security measures. The ease of conducting such attacks is attributed to the widespread availability of powerful computers and various malicious tools. The article compares several technology types and examines blockchain-based approaches to firmware enhancement, addressing their limitations such as large storage requirements and centralized firmware storage.

Additionally, the study in [17] outlines a general architectural framework for Internet of Healthcare Industry (IoH) applications, incorporating blockchain technology, Local Differential Privacy, and cloud computing (Icedrive). The study highlights the potential uses and challenges in integrating blockchain and cloud computing into IoT applications while also considering the application of blockchain in the future of the healthcare industry. This research is anticipated to facilitate the development of blockchain-based IoT applications.

At present, distinct blockchains within the same network lack the capability to seamlessly interact with each other. For instance, the exchange of data between Ripple and Ethereum remains infeasible. Furthermore, achieving blockchain interoperability entails navigating intricate procedures.

## III. METHODOLOGY

A patient-centered approach has been put into practice, wherein patients take responsibility for controlling access to their Electronic Health Records (EHRs). The architectural plan is designed around the concept of hospitals using distinct EHR platforms. Both platforms require healthcare participants to register through smart contracts or chain code. The attending physician engages in consultations with the relevant patients and inputs their EHRs into the system. These EHRs are then hashed, and the resulting hash value is used to create a blockchain block, establishing ownership of the EHR. The proposal suggests dividing the EHR into offline and online sections, with the patient's identity characteristics linked to the offline data during online data uploads. Any document-oriented database can be used to store the offline data. Access requests to the electronic health record are routed to the patient for approval when initiated by a system participant. Patients retain control over their Electronic Health Records (EHRs) and can determine who has access to their records and the extent of information shared. A crucial element in our system is the use of hash locks, particularly when connecting to an EHR from an external system. For instance, if a stakeholder from System B requires access to a patient's EHR in System A, a hash lock is created for that specific EHR, as outlined in study [18]. This hash lock grants the stakeholder in System B access to the patient's EHR, facilitating information retrieval. Fig. 1 provides a graphical representation of our architecture, illustrating how blockchain technology can streamline the exchange of electronic health records.

Proposed system has two major components. The system design along with appropriate representation and explanation has been given below:
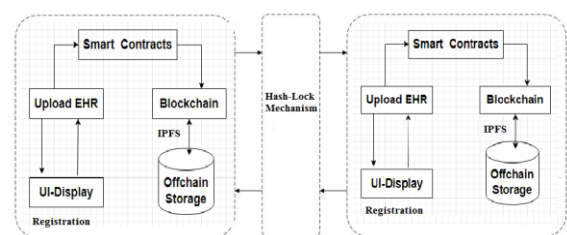


Fig. 1.    Electronic health record framework.

### A.  Smart Contract Structure

Within a specific hospital's smart contract, two distinct user types are present: Doctors and Patients. Users can register themselves via the user interface and receive a private-public key pair to facilitate secure data sharing. Once registered, users can log in using their credentials, granting them access to their respective functionalities, as detailed in study [19]. Doctors have the ability to create records and perform record searches, while Patients can access their own records and share data when required.

The execution of these functions is achieved through a Solidity contract, accessed via a Python script. To ensure data security during storage and retrieval, a secure approach is maintained by utilizing the IPFS protocol. Data is securely stored on IPFS and the resulting hashes are recorded within the Ethereum blockchain for traceability and verification purposes. Fig. 2 illustrates the architecture of an individual smart contract.
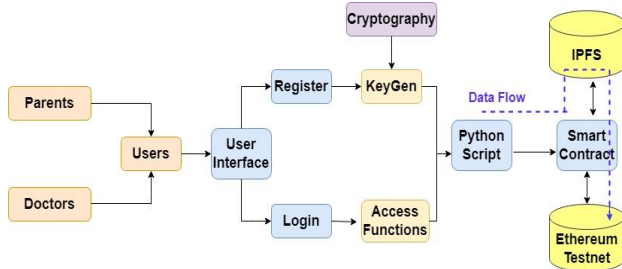


Fig. 2. Architecture flow of individual smart contract.

Certainly, the individual smart contract that operates within the context of a specific hospital for managing user interactions between Doctors and Patients, the individual smart contract streamlines the interactions between healthcare providers (Doctors) and patients, enhancing communication and data sharing. Patients have greater control over their medical records, promoting privacy and data autonomy [20, 21].The integration of IPFS and Ethereum blockchain ensures data security, traceability, and transparency. In essence, the individual smart contract serves as a pivotal component within Hospital X's digital infrastructure, providing a secure, efficient, and transparent means of managing medical records and interactions between healthcare providers and patients. Fig. 3 shows the flow of the user interface.
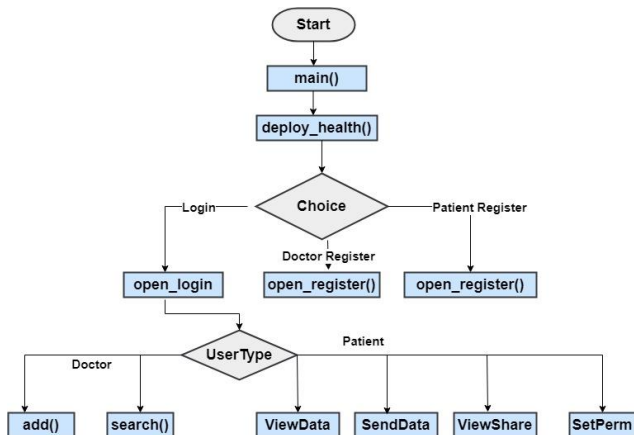


Fig. 3. Flow of the user interface.

### B. Cross-Chain Interoperability

When two or more blockchain networks or platforms are able to interact with one another without any hitches in the flow of information or transactions, we say that they are cross-chain interoperable. It addresses the challenge of isolated blockchains that operate independently and cannot directly interact with each other [22, 23]. Achieving cross-chain interoperability is crucial for creating a more connected and efficient blockchain ecosystem.

Different blockchain networks, such as Ethereum, Binance Smart Chain, Polkadot, and others, have their own protocols, consensus mechanisms, and features. Traditional blockchains operate in isolation, and transactions within a specific blockchain are not easily accessible or verifiable by other blockchains. Cross-chain interoperability aims to enable communication, data sharing, and asset transfers across multiple blockchain networks.

### C. Interoperability Structure

In Fig. 4, the architecture of the interoperability approach is depicted. It involves an Intermediate Contract that holds the Name, network, and address of each hospital contract. Every hospital must register its details with the intermediate contract. When Hospital A requires access to data from Hospital B, the following steps occur:

- Switch to the Intermediate contract network.

- Retrieve the network and address of Hospital B.

- Switch to the network of Hospital B.

- Retrieve the contents from Hospital B's contract.

- Revert back to the original contract network and return the data.

This process allows for secure and controlled data sharing between different hospital contracts.
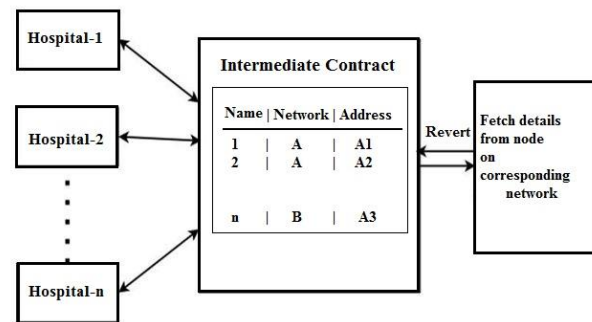


Fig. 4. Architecture of interoperability approach.

### D. Approaches to Cross-Chain Interoperability:

Atomic Swaps: These allow users to directly exchange assets between different blockchains without the need for intermediaries. Wrapped Tokens: Tokens on one blockchain are "wrapped" to create a representation on another blockchain, enabling their use in a different ecosystem. Sidechains: Separate blockchains, known as sidechains, are linked to the main blockchain, allowing for specific tasks to be performed on the sidechain while retaining the connection to the main chain. Cross-chain Bridge: Specialized smart contracts act as bridges between different blockchains, facilitating the transfer of assets and data. Polkadot and Cosmos: These platforms are designed with native cross-chain interoperability features, allowing multiple blockchains to be connected within a larger network.

Cross-chain interoperability enables the use of specialized features from different blockchains within a unified ecosystem. Assets can be moved seamlessly between

blockchains, enabling more efficient trading and utilization. Interoperability can help alleviate congestion on a single blockchain network by distributing transactions across multiple chains. Cross-chain interoperability supports collaboration between different projects and platforms, fostering innovation [24, 25]. Cross-chain interoperability plays a vital role in overcoming the limitations of isolated blockchains and creating a more interconnected and versatile blockchain landscape. As the blockchain ecosystem continues to evolve, solutions for cross-chain communication and data sharing will be crucial for achieving widespread adoption and realizing the full potential of decentralized technologies.

## IV. RESULTS AND DISCUSSION

The effectiveness of the suggested model is measured in terms of the following indicators. The success of a blockchain network may be measured by the following indicators, which have been developed with consideration for real-world use cases:

### A. Transaction Throughput

This indicator tracks how many deals the blockchain can handle in a given time frame. It's a measure of the network's ability to process several transactions at once.

### B. Latency

Latency refers to the time taken for a transaction to be confirmed and included in the blockchain. Lower latency signifies quicker transaction validation and responsiveness of the network.

### C. CPU Utilization

CPU usage is the rate at which a network's nodes use their central processing units. In our current use-case, each Hospital is associated to one smart contract instance. This smart contract provides various functionalities as required for the user operations. Each of these functions is explained in detail below:

### D. Register

This function handles registration of the new users. For every new user created, it generates a key pair i.e., private key and the public key which will be used for data encryption and decryption. This function triggers the Register() in the smart contract which works as follows:

```
Function Register(UserDetails, keys, flag):
    For i = 0 to Number of Users:
        User = ith User
        If k256(User.username) == k256(UserDetails.username):
            Return False  // Username is already in use
    Add UserDetails to UserList
    If flag == 1:
        Add UserDetails to Ddetails  // For doctors
    Else:
        Add UserDetails to Pdetails  // For patients
    Return True  // Registration successful
```

After the execution of the above function, it displays the corresponding success/fail message. Following is a preview of the register window shown in Fig. 5.
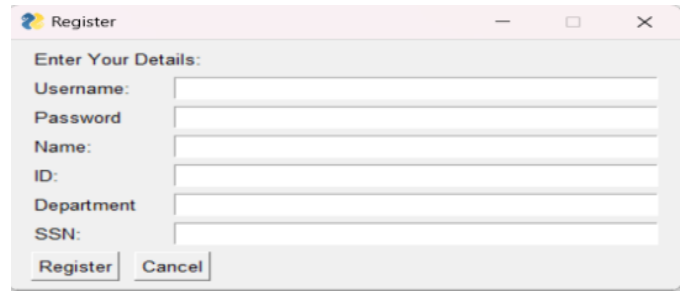
Fig. 5. Register window.

### E. Login

This function handles the login functionality for the existing users if the credentials provided are valid. It first triggers the Login() in the smart contract which works as follows:

```
Function Login(username, password):
    For i = 0 to Number of Users:
        User = ith User
        If  k256(User.username)  ==  k256(username)  &&
User.password == k256(password):
            Return UserType  // Successful login, return user type
        End If,
    End For
        Return  FailMessage   // Login failed, return a failure
message
```

The login window appears as shown in Fig. 6. If the login is successful, the above function returns the user type as doctor or patient. If the type is doctor then available functionalities will be add and search, and if the type is patient then available functionalities will be View-data, Send-data, view-share and set-permission.
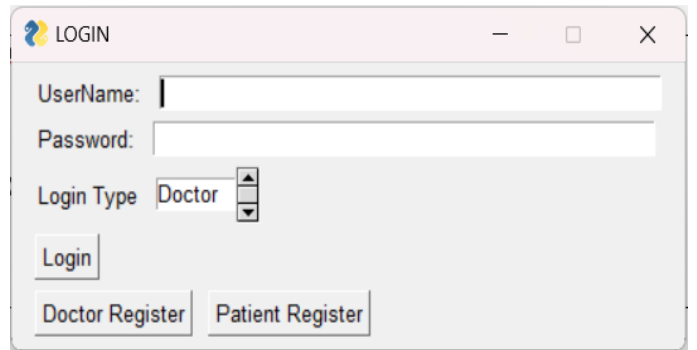
Fig. 6. Login window.

### F. Add Record

This function handles the addition of new records. It is executable only if the user type is doctor. The doctor enters the required details in the form provided as shown in Fig. 8. Doctors can also upload files using the provided option. The file is uploaded to the IPFS Server which returns a hash. These details along with the address hash are converted to a JSON record. This record is again hashed using IPFS. Then AddRecord() is triggered in the smart contract which works as follows and UI is shown in the Fig. 7.

*(IJACSA) International Journal of Advanced Computer Science and Applications,*
*Vol. 14, No. 10, 2023*

```
Function AddRecord(hash, PID):
    Add the record to the Records array
    If PID is present in the Hashlist:
        Add the current index to the corresponding PID in
Hashtable
        Set the flag
    If flag is not set:
Push the PID and current index to the Hashtable as a new
entry
```
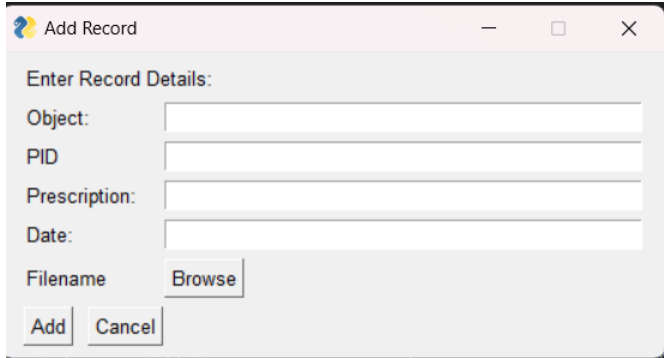


Fig. 7.    Add record window.

### G. Search Record

This function is used for searching and displaying patient records in tabular form. The search operation can be done based on two parameters, PID or SSN. For internal references, searching is done using PID, whereas, for cross-chain references, searching is done through SSN.

For the purpose of this explanation, let's focus on the internal reference using PID. First, a "Filtered Data" array is created to store the records that match the given pid. Then, the function iterates through a hash table that contains patient records. For each record in the hash table, the function checks if the pid matches the given pid. If there is a match, the function loops through all the indexes associated with the given pid. It pushes all matching records to the Filtered Data array. After all records have been checked, the function returns the Filtered Data array containing all the records that matched the given pid or returns error output as shown in Fig. 8. The pseudo code for SearchRecord() is as follows:

```
Function SearchRecord (PatientRecords, GivenPID):
    Create an empty array called FilteredData
        For each record in PatientRecords:
        If record.PID matches GivenPID:
            For each index associated with GivenPID:
                Add the matching record to FilteredData
        If FilteredData is not empty:
        Return FilteredData
    Else:
        Return ErrorOutput
```
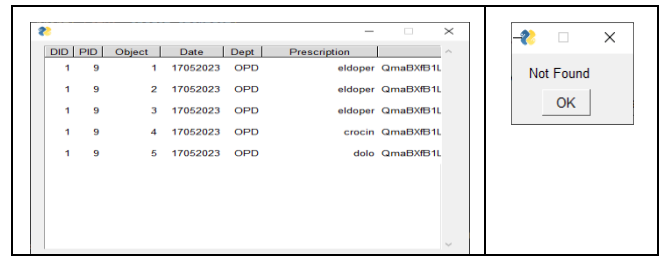


Fig. 8.    Output for search record (positive and negative).

### H. Interoperability Operations

Certainly, let's elaborate on the provided pseudocode steps and explain the process in detail:

*1) Retrieving SSN with getSSN()*: The first step involves retrieving the Social Security Number (SSN) associated with the provided Patient ID (pid). This information is obtained by executing the getSSN() function. This function likely queries a smart contract or database to fetch the SSN based on the given patient ID.

*2) Switching to intermediate network*: After obtaining the SSN, the pseudocode suggests disconnecting from the current network. This indicates a transition from the main network to an intermediate network, which acts as a backup or alternative in case of network downtime or delays.

*3) Choosing an intermediate network*: Users are presented with the option to choose between two intermediate networks: Sepolia and Goerli. These networks serve as contingency plans, ensuring that even if one network experiences issues, the process can continue using the other network.

*4) Connecting to intermediate network*: Based on the user's selection, the pseudocode connects to the corresponding intermediate network (Sepolia or Goerli).

*5) Accessing intermediate contract*: Once connected to the chosen intermediate network, the pseudocode suggests accessing a previously deployed intermediate contract. This contract likely contains functions and logic required for the subsequent steps.

*6) Retrieving list of hospitals*: Within the intermediate contract, the pseudocode fetches a list of all hospitals using the GetH() function. This list likely contains identifiers or addresses of different hospital contracts.

*7) Iterating over hospitals*: For each hospital in the retrieved list, the pseudocode enters a loop. This loop iterates through the list of hospitals one by one.

*8) Switching to hospital network*: Within the loop, the pseudocode disconnects from the current intermediate network and connects to the network associated with the specific hospital's contract. This allows interaction with the smart contract of the hospital.

*9) Searching and adding records*: With access to the hospital's network, the pseudocode utilizes the SearchRecordSSN() function. This function likely searches for medical records associated with the retrieved SSN and adds any matching records to a temporary storage.

285 | P a g e
www.ijacsa.thesai.org

*10)Completing hospital search*: Once records have been searched and added for the current hospital, the pseudocode disconnects from the hospital's network and reconnects to the intermediate network.

*11)Displaying stored records*: After searching all hospitals, the pseudocode ends the loop and reconnects to the original network. The medical records that have been temporarily stored during the search process are now displayed to the user for viewing.

*12)Visualization*: The entire process described above, from SSN retrieval to displaying records, can be visualized using a diagram or flowchart, shown in Fig. 9.

In summary, the pseudocode outlines a process where the SSN of a patient is used to search for and retrieve medical records from multiple hospitals' contracts. It employs intermediate networks and contracts to ensure data availability and accessibility even in the face of network issues. The process involves several steps of switching networks, accessing contracts, and iterating through hospitals to ultimately present the user with the aggregated medical records.

The pseudocode for the logic is given below:

```
Function Interoperable()
Input:
pid = GetUserInput()  // Get the Patient ID from the user.
// Retrieve SSN
SSN = GetSSN(pid)  // Call a function to retrieve SSN based
on the PID.
 // Disconnect from the current network
Network.Disconnect()
// Connect to the intermediate network
Network.Connect('intermediate')
// Get a list of hospitals from the intermediate contract
 Hosplist = IntermediateContract.GetHospitalList()
// For each hospital in the Hosplist
For i in Hosplist:
 nw, link = i[1], i[2]   // Get the network name (nw) and
contract address (link).
Network.Disconnect()
// Connect to the hospital's network
 Network.Connect(nw)
// Access the hospital's smart contract
 Temp = SmartContract.At(link)
 // Search for patient records using SSN
 Records = Temp.SearchRecordSSN(SSN)
Network.Disconnect()
// Reconnect to the original network
Network.Connect(curNetwork)
```
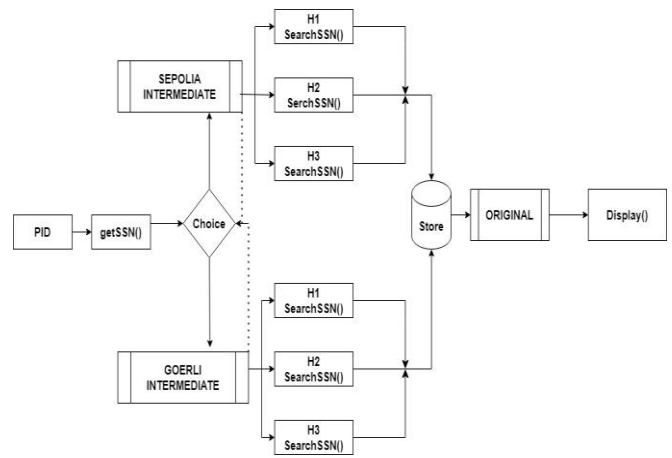


Fig. 9.   Interoperability implementation.



Fig. 10.  Transaction flow during cross-chain call.

In the figure given above Fig. 10, shows clearly about the transaction calls that take place. In current scenario the example encompasses three hospital contracts, in Sepolia and Goerli respectively. The intermediate contract is deployed on Sepolia as well. Certainly, here's an elaboration of the cross-chain search operation we have outlined:

Cross-Chain Search Operation Steps:

*1)  Initial network setup*

- The network is initially set to Sepolia, representing the primary network for the operation.

*2)  Switch to intermediate contract network*

- To ensure a robust and reliable search operation, the process begins by connecting to the intermediate contract network, which is also Sepolia in this case.

*3)  Fetching list of hospitals*

- Using the intermediate contract on the Sepolia network, the pseudocode fetches a list of hospitals: H1, H2, and H3. These hospitals represent the targets for the cross-chain search.

*4) Searching hospital 1 (sepolia)*

- The network connection switches to Hospital 1's network on Sepolia.

- The search transaction, likely involving the SearchRecordSSN() function, is executed for the patient's records associated with the retrieved SSN.

- Once the search transaction is confirmed, the retrieved records from Hospital 1 are temporarily stored.

*5) Searching hospital 2 (sepolia)*

- The network connection switches to Hospital 2's network on Sepolia.

- The search transaction for the same patient's records is executed within Hospital 2's network.

- After confirmation, the records from Hospital 2 are also temporarily stored.

*6) Searching hospital 3 (goerli)*

- The network connection switches to Hospital 3's network on Goerli. This represents a change in network from Sepolia to Goerli, emphasizing cross-chain operation.

- The search transaction for the same patient's records is executed within Hospital 3's network on the Goerli chain.

- Once confirmed, the records from Hospital 3 on the Goerli chain are temporarily stored.

*7) Aggregating and returning records*

- After successfully searching across multiple hospitals and networks, the temporary storage of retrieved records is aggregated.

- The aggregated records are then returned to the user, presenting a comprehensive overview of the patient's medical data from all the participating hospitals and chains.

This cross-chain search operation demonstrates the flexibility and versatility of the proposed model, allowing for seamless interaction with multiple hospital networks on different blockchain platforms (Sepolia and Goerli, in this case). By employing intermediate contracts and network switches, the model ensures data availability and continuity, even if issues arise in individual networks, enabling efficient retrieval and presentation of medical records across various chains.

Fig. 11 and Fig. 12 show the time taken for the operations GetH(), network switching and Searching times. These visual representations clearly indicate that fetching times and switching times are very low compared to the major search transaction.



Fig. 11. Transaction logs with time measures.
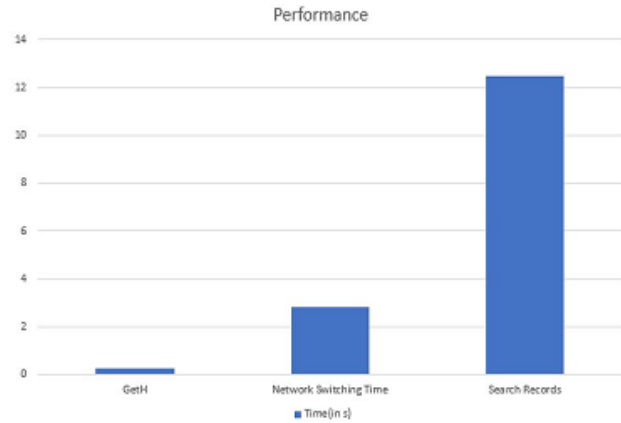


Fig. 12. Average time taken for operations.

TABLE I.    PERFORMANCE ANALYSIS FOR NUMBER OF RECORDS SEARCHED

| Hospitals | Record 1 | Record 2 | Record 3 |
|---|---|---|---|
| 1 | 15.53 | 15.63 | 15.66 |
| 2 | 30.12 | 30.33 | 30.45 |
| 3 | 45.45 | 45.66 | 45.89 |
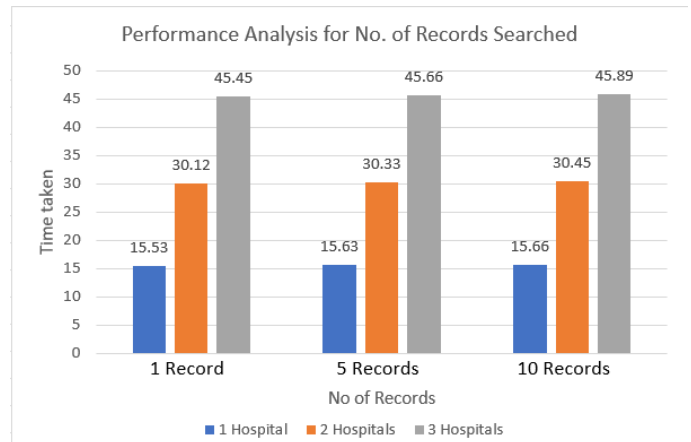


Fig. 13. Performance analysis for number of records searched.

The study involved measuring the average time required for searching records while varying the number of hospitals and records involved. It was observed that the search time was independent of number of records being searched shown in Table I and Fig. 13. The time taken was directly proportional to the number of hospitals involved in the search. This shows that the actual search operation takes place in the order of milliseconds but the majority of the time is due to transaction delay. The time taken for each of the above operations can be optimized if the average time taken for each transaction is relatively reduced by the Ethereum network.

## I. Average Latency Comparison

Fig. 14 displays the results of measurements of the delay required to perform various blockchain operations locally as well as between blockchain networks. The Ethereum test bed consists of two virtual computers running on the same physical computer, each of which hosts a different set of test network components. Fig. 14 shows that the suggested approach requires between 4s and 50ms to complete the transaction across the two blockchains, whereas a local transfer on Ethereum requires just 14ms. Therefore, although there is a significant increase, 4s for a transaction in the analyzed use case is manageable.
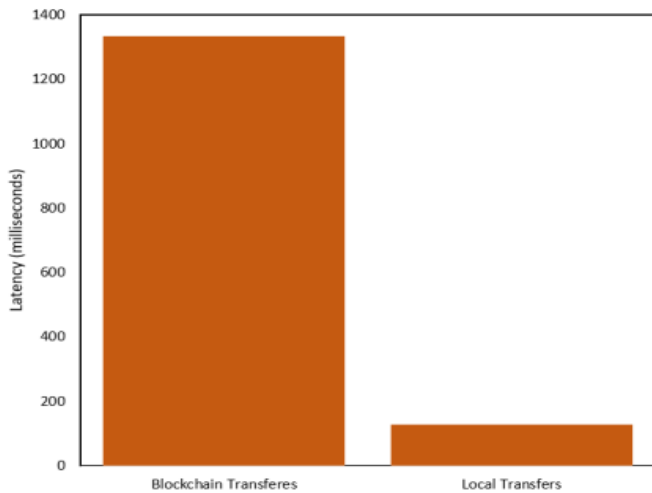


Fig. 14. Latency assessment.

Table II and Fig. 15 provide an illustration of the total CPU utilization for both test networks, denoted as B1 and B2. Throughout the test period, B1 exhibits a CPU consumption of around 66%. As the transaction load increases, this utilization gradually climbs and peaks at approximately 74%. In contrast, B2, involving the operation of four healthcare entities, exhibits a higher CPU consumption of around 80% when the transaction load is 500. This stands as a 10% increase over B1 at the same transaction load. With a rise in the transaction load, B2's CPU consumption further escalates. At a transaction load of 6000, B2's CPU utilization reaches approximately 86%, leading to the occurrence of an average of 411 failed transactions. In conclusion, the findings emphasize the importance of considering and to optimizing CPU resources as the network accommodates a larger number of participants or entities.

TABLE II. CPU UTILIZATION

| Transaction Rate | CPU Utilization | |
| --- | --- | --- |
| | B1 | B2 |
| 1000 | 67 | 78 |
| 2000 | 66 | 80 |
| 3000 | 70 | 80 |
| 4000 | 71 | 83 |
| 5000 | 73 | 85 |
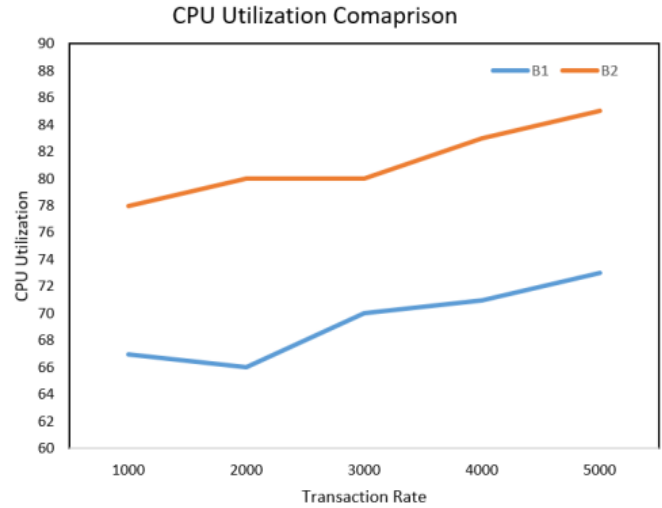


Fig. 15. CPU Utilization.

## V. CONCLUSION AND FUTURE SCOPE

In conclusion, the utilization of blockchain technology introduces a promising solution to address the persistent challenges of interoperability and privacy within Electronic Health Records (EHR). This technology empowers patients by granting them centralized access to their medical histories while simultaneously relieving healthcare providers of the lifelong responsibility of safeguarding medical data. Nevertheless, current implementations of blockchain-based EHR systems can address crucial concerns such as efficiency, fairness, and trust. Integrating blockchain with EHR is a multifaceted issue that surpasses the realm of technical expertise and requires collaboration from various stakeholders. To counteract the challenge of non-interoperability, our approach involves constructing a bridge between two similar blockchain networks. Proposed approach illustrates the solution through an EHR Structure, stored across distinct Ethereum Testnets, and enacted via a Solidity Smart Contract. This enables to establish the feasibility of bridging the gap and fostering a seamless interoperability experience between different blockchain networks. The main intention is to utilize a smart contract to embody the EHR Structure specific to individual hospitals. However, the need arises for deploying separate smart contracts for each hospital. Ensuring effective communication between these smart contracts presents a complex challenge, whether within a single blockchain or spanning multiple blockchains. The presented protocol successfully achieves objectives such as privacy conservation, time-controlled annulment, search

functionality, and data security, according to by our extensive security study. It is very resistant to both large-scale and low-key attempts to breach its security. There appears to be an opportunity for the integration of various blockchains to enable the sharing of Electronic Health Records (EHR) within a healthcare consortium from an external viewpoint. The emphasis is on achieving heightened security and efficiency, which could be compared comprehensively with existing solutions in this domain. This ongoing effort seems dedicated to refining the approach for the advantage of the healthcare industry and its stakeholders.

REFERENCES

[1] Agarwal, A., R. Joshi, H. Arora, and R. Kaushik. "Privacy and Security of Healthcare Data in Cloud Based on the Blockchain Technology." 2023 7th International Conference on Computing Methodologies and Communication (ICCMC), Erode, India vol. 2023: 87–92.

[2] Aich, S., N. K. Sinai, S. Kumar, M. Ali, Y. R. Choi, M. Joo, and H. Kim. "Protecting Personal Healthcare Record Using Blockchain and Federated Learning Technologies." 2021 23rd International Conference on Advanced Communication Technology (ICACT), Pyeongchang, Korea (South) vol. 2021: 109–12.

[3] Puneeth, R. P., and Parthasarathy, G. "Security and Data Privacy of Medical Information in Blockchain Using Lightweight Cryptographic System" *International Journal of Engineering*, *36*(5), 925-933, 2023 doi: 10.5829/ije.2023.36.05b.09

[4] Baskar, S., and P. V. Gopirajan. "Application of Blockchain in Digital Healthcare." 2023 International Conference on Intelligent and Innovative Technologies in Computing, Electrical and Electronics (IITCEE), Bengaluru, India vol. 2023: 591–5. DOI: 10.1109/IITCEE57236.2023.10091070.

[5] Gangothri, B. N., K. P. Satamraju, and B. Malarkodi. "Sensor-Based Ambient Healthcare Architecture Using Blockchain and Internet of Things." 2023 10th International Conference on Signal Processing and Integrated Networks (SPIN), Noida, India vol. 2023: 543–6. DOI: 10.1109/SPIN57001.2023.10116867.

[6] Gul, M. J. J., A. Paul, S. Rho, and M. Kim. "Blockchain Based Healthcare System with Artificial Intelligence." 2020 International Conference on Computational Science and Computational Intelligence (CSCI), Las Vegas, NV, US vol. 2020: 740–1. DOI: 10.1109/CSCI51800.2020.00138.

[7] Gunanidhi, G. S., and R. Krishnaveni. "Improved Security Blockchain for IoT Based Healthcare Monitoring System." 2022 Second International Conference on Artificial Intelligence and Smart Energy (ICAIS), Coimbatore, India vol. 2022: 1244–7. DOI: 10.1109/ICAIS53314.2022.9742777.

[8] Gupta, K., N. Jiwani, M. H. U. Sharif, N. Adhikari, and N. Afreen. "Blockchain Technology in Healthcare Industry." 2022 International Conference on Emerging Trends in Engineering and Medical Sciences (ICETEMS), Nagpur, India vol. 2022: 24–8. DOI: 10.1109/ICETEMS56252.2022.10093377.

[9] Haddad, A., M. H. Habaebi, M. R. Islam, and S. A. Zabidi. "Blockchain for Healthcare Medical Records Management System with Sharing Control." 2021 IEEE 7th International Conference on Smart Instrumentation, Measurement and Applications (ICSIMA), Bandung, Indonesia vol. 2021: 30–4. DOI: 10.1109/ICSIMA50015.2021.9526301.

[10] Haidar, M., and S. Kumar. "Smart Healthcare System for Biomedical and Health Care Applications Using Aadhaar and Blockchain." 2021 5th International Conference on Information Systems and Computer Networks (ISCON), Mathura, India vol. 2021: 1–5. DOI:

[11] Iftikhar, M., S. Tahir, F. Alquayed, and B. Hamid. "Blockchain and LDP Based Smart Healthcare IoT Applications: Architecture, Challenges and Future Works." 2023 International Conference on Business Analytics for

[12] Khujamatov, K., E. Reypnazarov, N. Akhmedov, and D. Khasanov. "Blockchain for 5G Healthcare Architecture." 2020 International Conference on Information Science and Communications Technologies (ICISCT), Tashkent, Uzbekistan vol. 2020: 1–5. DOI:

[13] Lee, A. R., M. G. Kim, K. J. Won, I. K. Kim, and E. Lee. "Coded Dynamic Consent Framework Using Blockchain for Healthcare Information Exchange." 2020 IEEE International Conference on Bioinformatics and Biomedicine (BIBM), Seoul, Korea (South) vol. 2020: 1047–50. DOI: 10.1109/BIBM49941.2020.9313330.

[14] Liu, Jingwei, Weiyang Jiang, Rong Sun, Ali Kashif Bashir, Mohammad Dahman Alshehri, Qiaozhi Hua, and Keping Yu. May 2023. "Conditional Anonymous Remote Healthcare Data Sharing over Blockchain." in *IEEE Journal of Biomedical and Health Informatics* 27, no. 5: 2231–42.

[15] Marry, P., K. Yenumula, A. Katakam, A. Bollepally, and A. Athaluri. "Blockchain Based Smart Healthcare System." 2023 International Conference on Sustainable Computing and Smart Systems (ICSCSS), Coimbatore, India vol. 2023: 1480–4.

[16] Puneeth, Reval Prabhu, and Parthasarathy Govindaswamy. "Survey on Security and Interoperability of Electronic Health Record Sharing Using Blockchain Technology." *Acta Informatica Pragensia* 12, no. 1 (2023): 160-78.

[17] Mukherjee, A., R. Halder, J. Chandra, and S. Shrivastava. "HealthChain: A Blockchain-Aided Federated Healthcare Management System." 2023 IEEE International Conference on Blockchain and Cryptocurrency (ICBC), Dubai, United Arab Emirates vol. 2023: 1–5.

[18] Ramar, K., G. P. V, H. Shanmugasundaram, B. P. Andraju, and S. Baskar. "Digital Healthcare Using Blockchain." 2022 1st International Conference on Computational Science and Technology (ICCST), CHENNAI, India vol. 2022: 651–5.

[19] Ren, J., J. Li, H. Liu, and T. Qin. August 2022. "Task Offloading Strategy with Emergency Handling and Blockchain Security in SDN-Empowered and Fog-Assisted Healthcare IoT." in *Tsinghua Science and Technology* 27, no. 4: 760–76. DOI: 10.26599/TST.2021.9010046.

[20] Sheeraz, M. M., M. A. I. Mozumder, M. O. Khan, M. U. Abid, M.-I. Joo, and H.-C. Kim. "Blockchain System for Trustless Healthcare Data Sharing with Hyperledger Fabric in Action." 2023 25th International Conference on Advanced Communication Technology (ICACT), Pyeongchang, Korea, Republic of vol. 2023: 437–40.

[21] Sinha, A., A. Patel, and M. Jagdish. "Application of Blockchain in Healthcare." 2022 First International Conference on Artificial Intelligence Trends and Pattern Recognition (ICAITPR), Hyderabad, India vol. 2022: 1–4. DOI: 10.1109/ICAITPR51569.2022.9844186.

[22] Suciu, G., M. Balanescu, S. Mitroi, D. Trufin, M. Falahi, C. Serban, and N. Goga. "An Overview of Blockchain Technology in STAMINA Project." 2022 IEEE International Conference on Blockchain, Smart Healthcare and Emerging Technologies (SmartBlock4Health), Bucharest, Romania vol. 2022: 1–4.

[23] Tidke, S. K., V. Khedkar, A. Banerjee, A. Mulik, A. Goyal, and Y. Chhabaria. "An Interactive and Secure Blockchain Web Portal for Online Healthcare Services." 2022 International Conference on Decision Aid Sciences and Applications (DASA), Chiangrai, Thailand vol. 2022: 454–9. DOI: 10.1109/DASA54658.2022.9764973.

[24] Mousa Mohammed Khubrani, "Artificial Rabbits Optimizer with Deep Learning Model for Blockchain-Assisted Secure Smart Healthcare System" International Journal of Advanced Computer Science and Applications(IJACSA), 14(9), 2023. http://dx.doi.org/10.14569/IJACSA.2023.0140998.

[25] Zhu, T.-L., and T.-H. Chen. "A Patient-Centric Key Management Protocol for Healthcare Information System Based on Blockchain." 2021 IEEE Conference on Dependable and Secure Computing (DSC), Aizuwakamatsu, Fukushima, Japan vol. 2021: 1–5. DOI: 10.1109/DSC49826.2021.9346259

# A Comparison of Sampling Methods for Dealing with Imbalanced Wearable Sensor Data in Human Activity Recognition using Deep Learning

Mariam El Ghazi[*], Noura Aknin

Information Technology and Modeling, Systems Research Unit, Abdelmalek Essaadi University, Tetouan, Morocco

*Abstract*—**Human Activity Recognition (HAR) holds significant implications across diverse domains, including healthcare, sports analytics, and human-computer interaction. Deep learning models demonstrate great potential in HAR, but performance is often hindered by imbalanced datasets. This study investigates the impact of class imbalance on deep learning models in HAR and conducts a comprehensive comparative analysis of various sampling techniques to mitigate this issue. The experimentation involves the PAMAP2 dataset, encompassing data collected from wearable sensors. The research includes four primary experiments. Initially, a performance baseline is established by training four deep-learning models on the imbalanced dataset. Subsequently, Synthetic Minority Over-sampling Technique (SMOTE), random under-sampling, and a hybrid sampling approach are employed to rebalance the dataset. In each experiment, Bayesian optimization is employed for hyperparameter tuning, optimizing model performance. The findings underscore the paramount importance of dataset balance, resulting in substantial improvements across critical performance metrics such as accuracy, F1 score, precision, and recall. Notably, the hybrid sampling technique, combining SMOTE and Random Undersampling, emerges as the most effective method, surpassing other approaches. This research contributes significantly to advancing the field of HAR, highlighting the necessity of addressing class imbalance in deep learning models. Furthermore, the results offer practical insights for the development of HAR systems, enhancing accuracy and reliability in real-world applications. Future works will explore alternative public datasets, more complex deep learning models, and diverse sampling techniques to further elevate the capabilities of HAR systems.**

*Keywords—Human activity recognition (HAR); class imbalance; sampling methods; wearable sensors; deep learning; synthetic minority over-sampling technique (SMOTE); random undersampling; PAMAP2 dataset; bayesian optimization*

## I. INTRODUCTION

Human Activity Recognition (HAR) is a multidisciplinary field focused on the automated identification and categorization of human activities, primarily relying on data collected from diverse sensors. Its applications extend into critical domains, particularly Sports or healthcare [1]. The automatic detection and classification of human activities can significantly improve the quality of life for elderly individuals and dependents, enhancing their safety, well-being, and independence [2].HAR systems play a vital role in smart home environments by providing context-aware services to residents, monitoring their activities, and alerting caregivers in case of any abnormal situations[3].

Deep learning models have revolutionized HAR due to their capacity to process and analyze sensor data effectively. Long Short-Term Memory (LSTM) networks and Convolutional Neural Networks (CNN) are two prominent deep learning architectures that excel at learning complex patterns and temporal dependencies from sensor data. These models have demonstrated remarkable performance in HAR, making them the focal point of this study [4] [5]. While deep learning models have shown promise in HAR, one significant challenge is posed by imbalanced datasets [6]. In many real-world scenarios, certain activities or classes are more frequent than others in the data, creating an imbalance. This imbalance can adversely affect the performance and accuracy of HAR models, as they may become biased towards the majority class, leading to poor recognition of minority activities [7].

In summary, Human Activity Recognition (HAR) holds vital implications for various domains. Deep learning models, such as LSTM and CNN, enhance HAR by effectively processing sensor data. The use of sampling techniques to address class imbalance significantly boosts model performance. This research underscores the importance of balanced datasets in HAR and provides practical insights for real-world applications.

The primary contributions of this study are as follows:

- The profound impact of class imbalance on the performance of deep learning models in HAR is investigated, and a range of sampling techniques designed to alleviate this issue is introduced and rigorously evaluated, offering valuable insights into enhancing model performance within imbalanced datasets.

- Three distinct sampling techniques are evaluated: SMOTE Random Undersampling, and a hybrid approach combining both methods.

- A detailed comparative analysis of the efficacy of these sampling methods in enhancing learning from imbalanced human activity data through deep machine learning algorithms is provided. Specifically, a test is conducted on Vanilla LSTM, 2 Stacked LSTM, 3 Stacked LSTM, and the Hybrid CNN-LSTM model.

The findings consistently demonstrate that the hybrid sampling techniques consistently outperform state-of-the-art models across critical performance metrics, including accuracy, precision, recall, and F1 score.

The paper is organized into distinct sections to effectively present the research findings. Section II presents the Related Works, reviewing prior research in the field related to the problem. Section III elaborates on the Materials and Methods employed in the experimental approach. Section IV presents the outcomes of the experiments and engages in a thorough discussion of the findings. Finally, in Section V, the Conclusion presents the key findings, and future directions of sensor -based HAR using deep learning models.

## II. RELATED WORK

In the field of Human Activity Recognition (HAR), addressing imbalanced data presents a significant challenge, a common issue observed in various public datasets, including Opportunity [8], WISDM V1.1[9], SPHERE [10] and PAMAP2 [11]. Imbalanced data can profoundly affect the performance of deep learning models utilized in HAR tasks. To tackle this challenge, several studies have explored the integration of deep learning models with sampling methods specifically designed for Human Activity Recognition based on sensor data.

Jeong et al. (2022) conducted a comprehensive study focusing on the influence of undersampling and oversampling techniques for classifying physical activities using an imbalanced accelerometer dataset. Their findings proposed that ensemble learning, coupled with well-defined feature sets and undersampling, exhibits robustness in the classification of physical activities within imbalanced datasets. This approach proves particularly effective in real-world scenarios, where imbalanced class distributions are commonplace. Furthermore, the study underscored the superiority of ensemble learning over other machine learning and deep learning models in handling small datasets with subject variability [12].

Hamad et al. (2020) evaluated the efficacy of imbalanced data handling methods in the context of deep learning applied to smart home environments. Leveraging a CNN LSTM model and a dataset comprising daily living activities collected from two real intelligent homes, their research demonstrated a significant performance improvement by applying the SMOTE oversampling method. This enhancement resulted in a notable increase in accuracy (from 0.60-0.62 to 0.71-0.73) when compared to training on the original imbalanced data [13].

Alani et al. (2020) delved into the classification of imbalanced multi-modal sensor data for HAR within smart home environments, using deep learning techniques in conjunction with oversampling (specifically, SMOTE) and undersampling methods. The results unequivocally favored the SMOTE method over undersampling in effectively addressing imbalanced data challenges within HAR tasks using the SPHERE dataset [14].

Alharbi et al. (2022) made significant contributions by investigating the effectiveness of oversampling methods, such as SMOTE and its hybrid variations, in improving the classification of minority classes in diverse datasets. For instance, on the PAMAP2 dataset, the MLP achieved an F1 score of 0.7185 using the SMOTE sampling method, compared to its baseline score of 0.7473. [7].

In addition to the aforementioned studies, recent research has showcased the potential of deep learning models for HAR:

- Wan et al. (2020) introduced deep models for real-time HAR using smartphones, including CNN and LSTM models, achieving high accuracies of 91.00% and 85.86%, respectively on the PAMAP 2 Dataset [15].

- Xu et al. (2022) proposed several methods, including classical CNN, LSTM, and Inception-LSTM with attention mechanisms, achieving F1 scores ranging from 0.8949 to 0.9513 [16].

- Tehrani et al. (2023) utilized a deep multi-layer Bi-LSTM model for sensor-based HAR, obtaining promising results with F1-score, Precision, Recall, and Accuracy all reaching 93.41% [17].

- Thakur et al. (2022) demonstrated that a hybrid model combining CNN and LSTM with an autoencoder for dimensionality reduction achieved an impressive F1 score of 0.9446 and an accuracy of 94.33% for HAR [4].

- Challa et al. (2022) proposed a multibranch CNN-BiLSTM model for human activity recognition using wearable sensor data, achieving an impressive accuracy of 94.29% [18].

Table I summarizes the performance of various deep learning models on the PAMAP2 dataset using different sampling methods for sensor-based HAR.

These studies collectively emphasize the positive impact of oversampling techniques, particularly SMOTE, in enhancing model performance when compared to training on imbalanced datasets. These insights lay the foundation for this research, which aims to build upon this foundation and further investigate the efficacy of sampling methods in improving the performance of deep learning models for HAR on the PAMAP2 dataset.

In the field of HAR, a significant gap in existing research has been found. There hasn't been enough focus on how different sampling techniques affect the performance of deep learning models in HAR. While some studies have tackled imbalanced data in HAR, they often overlook the critical role that sampling methods play. This gap highlights the need for a more thorough investigation into how sampling techniques and deep learning intersect in HAR. That's where the research steps in. The commitment is to address this gap by thoroughly studying how various sampling methods impact the performance of deep learning models in real-world HAR scenarios. The goal is to provide a clearer picture of how sampling methods and deep learning models work together, ultimately improving the accuracy and reliability of activity recognition in sensor-based applications.

TABLE I.    PREVIOUS STUDIES PERFORMANCE ON PAMAP2 DATASET USING DEEP LEARNING MODELS AND SAMPLING METHODS FOR SENSOR BASED HAR

| Study | year | Dataset | Classification method | Sampling method | Accuracy | F1 score | Precision | Recall |
|-------|------|---------|-----------------------|-----------------|----------|----------|-----------|--------|
| [14] | 2020 | SPHERE | CNN | NONE | 0.7030 | - | - | - |
| [14] | 2020 | SPHERE | LSTM | NONE | 0.6598 | - | - | - |
| [14] | 2020 | SPHERE | CNN-LSTM | NONE | 0.6829 | - | - | - |
| [14] | 2020 | SPHERE | CNN | SMOTE | 0.9355 | - | - | - |
| [14] | 2020 | SPHERE | LSTM | SMOTE | 0.9298 | - | - | - |
| [14] | 2020 | SPHERE | CNN-LSTM | SMOTE | 0.9367 | - | - | - |
| [14] | 2020 | SPHERE | CNN | UNDERSAMPLING | 0.2937 | - | - | - |
| [14] | 2020 | SPHERE | LSTM | UNDERSAMPLING | 0.3794 | - | - | - |
| [14] | 2020 | SPHERE | CNN-LSTM | UNDERSAMPLING | 0.3085 | - | - | - |
| [15] | 2020 | PAMAP2 | LSTM | NONE | 0.8580 | 0.8534 | 0.8651 | 0.8467 |
| [16] | 2022 | PAMAP2 | LSTM | NONE | 0.8920 | 0.8949 | 0.8969 | 0.8928 |
| [17] | 2023 | PAMAP2 | Bi-LSTM | NONE | 0.9341 | 0.9341 | 0.9341 | 0.9347 |
| [4] | 2022 | PAMAP2 | convLSTM AE | NONE | 0.9433 | 0.9446 | - | - |
| [18] | 2022 | PAMAP2 | CNN-BiLSTM | NONE | 0.9429 | - | - | - |
| [7] | 2022 | PAMAP2 | MLP | SMOTE | -- | 0.7473 | 0.7769 | 0.7493 |

## III. MATERIAL AND METHODS

In this research, the impact of class imbalance on HAR using wearable sensor data and deep learning models was investigated. To address this issue, three sampling methods were thoroughly examined: SMOTE, Random Undersampling, and a hybrid combination of the aforementioned techniques. The study involved the training of four deep learning models, including Vanilla LSTM, 2 Stacked LSTM, 3 Stacked LSTM, and Hybrid CNN-LSTM, on the PAMAP2 dataset. Through rigorous experimentation and evaluation, the aim was to identify the most effective sampling approach to improve model performance and generalization in HAR. The findings are expected to contribute valuable insights towards enhancing the accuracy and reliability of HAR systems deployed in real-world scenarios.

### A. PAMAP2 Dataset

The PAMAP2 dataset [11], which stands for "Physical Activity Monitoring using a Multipurpose Sensor" holds a prominent role in the realm of Human Activity Recognition (HAR) research. Its comprehensive data collection approach, diverse participant demographic, and meticulous data organization make it a valuable resource for the research community.

Here are some key characteristics of the PAMAP2 dataset, as extracted from the dataset documentation [11] :

- Participant Diversity: One noteworthy aspect of the PAMAP2 dataset is the diversity of its participant pool. This dataset comprises data contributed by both genders, with a broad age range spanning from 23 to 32 years. Moreover, it includes individuals with varying physical characteristics, such as weights ranging from 65 to 95 kilograms and heights spanning between 168 and 194 centimeters. This demographic diversity

empowers researchers to develop activity recognition models applicable to a broad spectrum of individuals.

- Data Collection: Researchers collected the dataset using a range of wearable sensors, including those worn on the wrist, chest, and ankle. These sensors operated at a high sampling rate of 100Hz, enabling the capture of an extensive volume of data, essential for detailed analysis of activities and movements (see Table II).

- Activity Variety: The PAMAP2 dataset offers an array of data related to various physical activities. It encompasses 12 distinct activity types, with detailed descriptions provided in Table III. This categorization serves as a valuable reference for activity labeling and model development.

- Data Format: The dataset is thoughtfully organized, with raw data from all sensors synchronized and labeled, and then consolidated into a single data file per participant and session. These files are presented in text format (.dat), simplifying structured data manipulation and analysis.

TABLE II.    PAMAP2 DATASET DESCRIPTION

| Dataset | Labels | Sampling Rate | Windows Size | Overlap | # Subjects |
|---------|--------|---------------|--------------|---------|------------|
| PAMAP2 | 12 | 100 Hz | 1s | 50% | 9 |

Table III provides an overview of the data distribution within the PAMAP2 dataset, highlighting a significant class imbalance among different activity labels in both the training and testing datasets. This issue is further underscored in Fig. 1, where it becomes evident that the "Rope jumping" activity exhibits notably fewer instances compared to other activities. This skewed data distribution can exert a substantial impact on the performance of deep learning models. Consequently, it becomes imperative to implement suitable sampling strategies to guarantee the reliability and accuracy of results.

TABLE III.     Data Distribution per Activity in the PAMAP2
Dataset

| Class id | Activity label | # Instances Training Set 70% | # Instances Testing Set 70% |
|---|---|---|---|
| 0 | Lying | 100298 | 42633 |
| 1 | Sitting | 58380 | 25358 |
| 2 | Standing | 70165 | 29808 |
| 3 | Walking | 86117 | 36789 |
| 4 | Running | 30100 | 12950 |
| 5 | Cycling | 63755 | 27585 |
| 6 | Nordic Walking | 78154 | 33678 |
| 7 | Ascending stairs | 41442 | 17872 |
| 8 | Descending stairs | 32800 | 14030 |
| 9 | Vacuum cleaning | 60703 | 26256 |
| 10 | Ironing | 87885 | 37343 |
| 11 | Rope jumping | 10889 | 4564 |
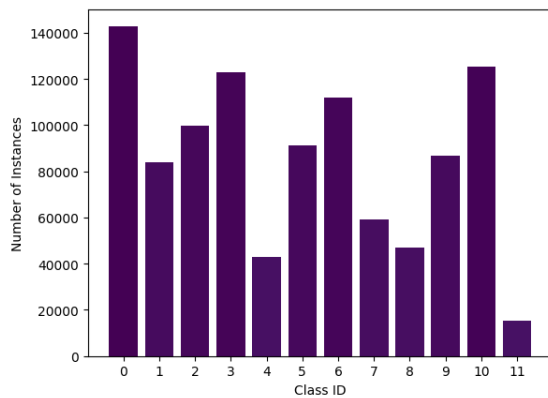


Fig. 1.     Data distribution by activity in PAMAP2 dataset.

## B.  Deep Learning Models

*1) Long short-term memory (LSTM)*: LSTM networks belong to the category of recurrent neural networks (RNNs) and hold significance in time series applications, particularly HAR, that involve the classification of activities based on sensor data, such as accelerometers and gyroscope readings from smartphones. The strength of LSTM networks in HAR lies in their capability to capture and model long-term dependencies present within the sensor data [19].

*2) Hybrid deep learning model (CNN-LSTM)*: This research harnesses the power of hybrid models, specifically the integration of Convolutional Neural Networks (CNN) and Long Short-Term Memory (LSTM) networks. This combination, as evidenced by several studies [14][4], holds promise for achieving high performance in HAR tasks. The rationale behind selecting this hybrid model is compelling: CNN excels at capturing spatial relationships within data, while LSTM is adept at modeling temporal dependencies. This combination allows us to leverage the strengths of both architectures [20]. One notable advantage of the hybrid model is that CNN accelerates the feature extraction process,

enhancing training efficiency. This synergy between CNN and LSTM contributes to the model's overall effectiveness in recognizing human activities based on sensor data.

*3) Deep learning models configurations:* In the following deep learning configuration for multiclass HAR classification, various layers play distinct roles. These include the LSTM layer, dropout layer, dense layer with Softmax activation for probability estimation, convolutional (Conv1D) layer, and max pooling layers. Each layer plays a specific role in a deep learning architecture for multiclass classification. The LSTM layer captures sequential dependencies in the data, making it suitable for time series or sequential data. The dropout layer helps prevent overfitting by randomly deactivating a fraction of neurons during training, enhancing the model's generalization. The dense layer, often found in the final stage, produces class scores. The softmax activation function applied to these logits converts them into class probabilities. The convolutional (Conv1D) layer extracts spatial features from the input data. Max pooling layers reduce the spatial dimensions while retaining essential information, aiding in feature selection and computational efficiency. Combined, these layers enable the deep learning model to process, understand, and classify data efficiently and accurately.

In this study, several configurations of deep learning models for HAR are explored. These configurations include:

*a) Vanilla LSTM*: This straightforward LSTM setup consists of a single hidden layer of LSTM units and an output layer for prediction. It has proven its effectiveness in various small sequence prediction tasks [21].

Fig. 2 illustrates the architecture of the Vanilla LSTM model. It provides a visual representation of the model's structure, showcasing the flow of data through its layers, including the LSTM layer, dropout layers, and dense layers, ultimately leading to the output layer for activity classification.
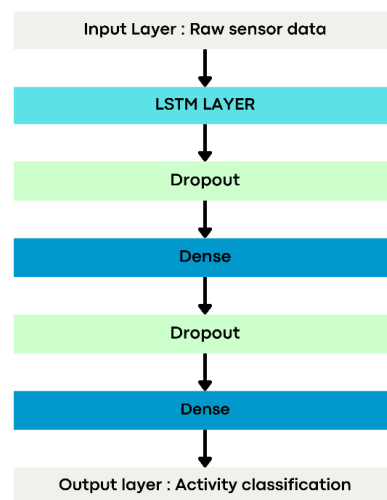


Fig. 2.   Structure of vanilla LSTM model.

*b) 2-Stacked LSTM*: Variants of the Stacked LSTM model, featuring two hidden layers, are also investigated in this study. Emerging from research findings, Stacked LSTM networks exhibit improved recognition efficiency by iteratively extracting temporal features [21].

Fig. 3 provides an overview of the 2-Stacked LSTM model's architecture. This model is specifically designed for Human Activity Recognition (HAR) and excels in capturing intricate temporal patterns within sensor data. It consists of two LSTM layers with 64 units each, enabling the understanding and modeling of complex temporal relationships. Dropout layers are strategically placed to prevent overfitting during training. The model then utilizes two Dense layers, with 96 and 12 units, for feature extraction and final classification. Overall, the 2-stacked LSTM model's structure is optimized for accurate and robust activity recognition in HAR applications.
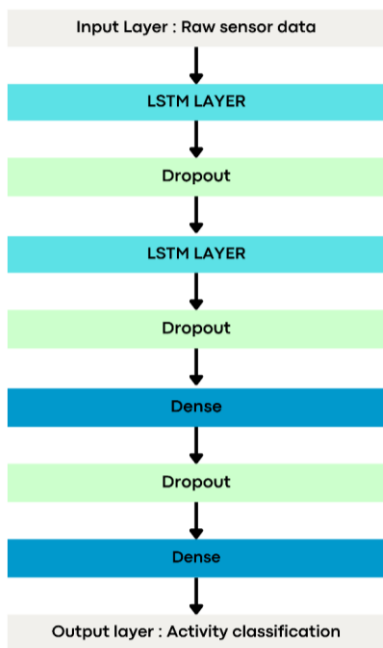


Fig. 3. Structure of 2-stacked LSTM model.

*c) 3-Stacked LSTM*: Similar to the 2-Stacked LSTM but with an additional layer of LSTM units, this configuration aims to further enhance the model's capacity for temporal feature extraction [21].

Fig. 4 provides an overview of the 3-Stacked LSTM model's architecture, designed for Human Activity Recognition (HAR). This model excels at capturing intricate temporal patterns within sensor data. It comprises three LSTM layers, each with 32 units, to model complex temporal relationships. Dropout layers are integrated to prevent overfitting during training. The model also includes two dense layers with 64 and 12 units, respectively, for feature extraction and final activity classification. In summary, the 3-Stacked LSTM model is engineered to achieve robust and accurate activity recognition in HAR scenarios by effectively handling temporal data dependencies and ensuring generalization through dropout mechanisms.
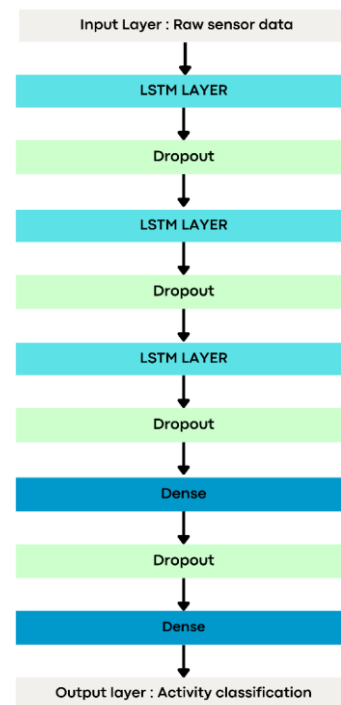


Fig. 4. Structure of 3-stacked LSTM model.

*d) Hybrid Model (CNN-LSTM)*: The CNN-LSTM model, a hybrid architecture that seamlessly combines Convolutional Neural Networks (CNN) and Long Short-Term Memory (LSTM) layers.

Fig. 5 outlines the Hybrid CNN-LSTM model for HAR. The architecture starts with a CNN layer followed by dropout and max pooling for feature extraction. Subsequently, an LSTM layer captures temporal patterns with dropout for regularization. The final dense layer performs activity classification. This design effectively handles spatial and temporal aspects of sensor data, ensuring robust activity recognition in HAR.
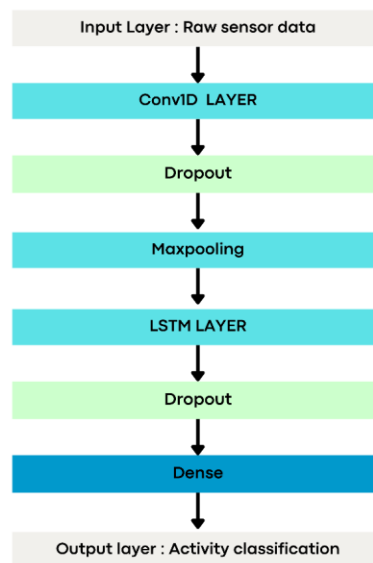


Fig. 5. Structure of hybrid CNN-LSTM model.

## C. Sampling Techniques

To tackle the challenge of imbalanced data, three different sampling techniques were applied:

*1) SMOTE (Synthetic minority over-sampling technique):* This Sampling technique serves as an effective tool for addressing imbalanced datasets in the realm of machine learning. Its function involves creating synthetic data points for the underrepresented class by bridging the gap between existing samples. In the context of sensor-based Human Activity Recognition (HAR) using deep learning, SMOTE plays a vital role in enhancing the classification accuracy of models like Multi-Layer Perceptrons (MLPs) [7].

Deep learning models require a high amount of data and are very sensitive to the imbalanced class problem. This is where SMOTE steps in, generating artificial samples for the minority class, thereby balancing the dataset and significantly improving the classification accuracy of these deep learning models [14].

*2) Random undersampling:* This Sampling method addresses imbalanced datasets by randomly removing samples from the majority class to achieve balance. In sensor-based Human Activity Recognition (HAR) with deep learning, is employed to boost deep learning model classification accuracy [14]. Deep learning models require a high amount of data and are sensitive to class imbalances. Thus, Random Undersampling eliminates samples from the majority class, balancing the dataset and improving classification accuracy [14]. However, this method can lead to the loss of critical information from the majority class, potentially impacting the model's classification accuracy [7]. Hence, it is crucial to carefully select the samples for removal to prevent the loss of vital information.

*3) Hybrid sampling:* Hybrid sampling is a technique used to deal with imbalanced datasets in machine learning. It involves combining oversampling and undersampling methods to balance the dataset. This method generates synthetic samples for the minority class using SMOTE and randomly removes samples from the majority class using Random Undersampling. The combination of these two methods helps to balance the dataset and improve the classification accuracy of deep learning models [7][14]. Hybrid sampling is particularly effective in sensor-based Human Activity Recognition (HAR) when combined with deep learning models. This technique successfully addresses the challenge of imbalanced classes while simultaneously mitigating the risk of losing valuable information from the majority class that can occur with random undersampling alone. By generating synthetic samples for the minority class through SMOTE, hybrid sampling ensures a well-represented minority class in the dataset. This balanced dataset significantly enhances the classification accuracy of deep learning models, while also promoting data diversity [14].

Table A1 in Appendix A provides a comprehensive overview of the dataset instances before and after the application of various sampling methods. The table allows for a clear visualization of how each sampling technique impacts the dataset composition.

## D. Hyperparameter Tuning with Bayesian Optimization

The Model Hyperparameters are crucial in deep learning, shaping training algorithms and model performance. Bayesian optimization offers an effective means to optimize these parameters, particularly in complex, function-based problems lacking simple analytical solutions. To apply Bayesian optimization to time series and sensor-based Human Activity Recognition (HAR) using LSTM models, the following steps can be followed:

Step 1: Define the hyperparameter search space.

Step 2: Specify the objective function to evaluate model performance.

Step 3: Initialize the Bayesian optimization algorithm with hyperparameter values.

Step 4: Iteratively use the algorithm to suggest hyperparameters for evaluation.

Step 5: Continue until predefined convergence criteria are met, like a set number of iterations or desired performance levels.

## E. Evaluation Metrics

In the experiment, various evaluation metrics were used to assess the HAR model's performance. These metrics included accuracy, F1 score, precision, recall, and the confusion matrix. These evaluation metrics determine the performance of a model on a dataset. The most common metric is the confusion matrix which is a two-dimension table of class labels; one represents the current class and the other represents the predicted one. Accuracy is the most used one to evaluate model classification. It defines a ratio of correct predictions and overall predictions. The accuracy can be a good measure when the dataset class is balanced. Otherwise, this metric is not appropriate for evaluation. In the case of imbalanced datasets, other metrics are used such as precision, recall, f-measure, and specificity. Table IV presents the definition of all these metrics [22].

Understanding these performance metrics requires knowledge of four fundamental terms used in their measurement: true positive (TP), true negative (TN), false positive (FP), and false negative (FN).

TABLE IV. PERFORMANCE METRICS

| Metric | Formula | Definition |
|---|---|---|
| Accuracy | $\dfrac{tp + tn}{tp + tn + fp + fn}$ | the ratio of correct predictions and overall predictions |
| Precision | $\dfrac{tp}{tp + fp}$ | the ratio of correct predictions to the total predicted |
| Recall of sensitivity | $\dfrac{tp}{tp + fn}$ | the ratio of correct predictions to the samples in the actual class |
| Specificity | $\dfrac{tn}{tn + fp}$ | The ratio of actual class 0 to the correctly predicted 0 |
| F1 score / F-measure | $\dfrac{2(recall * precision)}{recall + precision}$ | The weighted average of precision and Recall if the data is imbalanced |

## IV. Experiments and Results

### A. Experimental Design

This research aims to investigate the impact of data balancing techniques on the performance of deep learning models for Human Activity Recognition (HAR) by addressing the following research questions:

*1)* How does class imbalance affect the performance of deep learning models in Human Activity Recognition (HAR) when applied to wearable sensor data?

*2)* What are the comparative effects of different sampling techniques, such as SMOTE, Random Undersampling, and Hybrid Sampling, in addressing the class imbalance in wearable sensor data for HAR?

*3)* What role does hyperparameter tuning play in improving the accuracy and performance of deep learning models for HAR, particularly in the context of imbalanced datasets?

*4)* Which combination of sampling technique and hyperparameter tuning strategy yields the most significant performance improvements in HAR using deep learning models for imbalanced wearable sensor data?

The hypothesis guiding this study is that balancing the dataset will result in enhanced classification accuracy in HAR using deep learning models. The experiments were carried out using the PAMAP2 dataset collected from wearable sensors, encompassing wrist, chest, and ankle devices. Four deep learning models were employed: Vanilla LSTM, 2-Stacked LSTM, 3-Stacked LSTM, and CNN-LSTM.

### B. Experimental Setup

The conducted experiments are performed on an NVIDIA GPU V100 using the Google Collaboratory Pro+ platform. The four models' hyperparameters were optimized through Bayesian Hyperparameter Optimization, utilizing the Keras Tuner library[23]. The experiment setup is detailed in Table V.

TABLE V.    EXPERIMENTAL SETUP

| Platform | Google Colab Pro+ |
|---|---|
| **GPU** | NVIDIA GPU V100 |
| **RAM** | 15 GB |
| **Tenserflow version** | 2.12.0 |
| **Keras Version** | 2.12.0 |
| **Keras Tuner Version** | 1.3.5 |

### C. Experiment Pipeline

To evaluate the models' performance on the PAMAP2 dataset, a comprehensive experiment pipeline was executed.
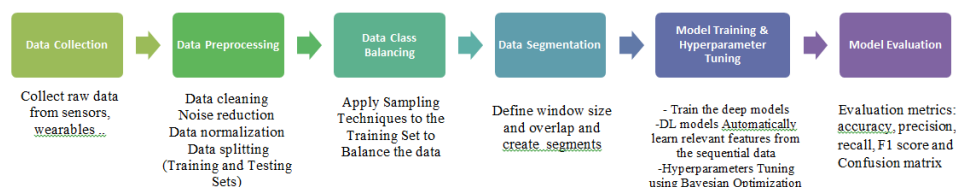
This pipeline is composed of multiple stages, each playing a vital role in the experiments (see Fig. 6):

*1) Data collection*: Initially, the raw sensor data from wearable devices were collected.

*2) Data preprocessing*: The dataset goes through a preprocessing phase, involving actions like data cleaning, noise reduction, and normalization.

During this stage, the raw sensor data from wearable devices is readied for the proposed model. The subject-specific files containing activity records are consolidated into one data frame. To adhere to PAMAP2 guidelines, invalid orientation columns are removed, and transient activity rows are dropped. Non-numeric data is transformed into numeric form, and missing values are interpolated to ensure data integrity. Scaling is applied to normalize input features, ensuring data uniformity. Labels are encoded and converted into categorical variables, a critical step for activity classification during model training.

The data is then split into training and testing sets, with 70% allocated for training and 30% for testing. Data is segmented into overlapping windows, with a window size of 1 second and a 50% overlap. This segmentation process creates segments and associated labels for both training and testing. The segments and labels are reshaped to align with the LSTM model's input format. The experiment validates the shape of training and testing segments before moving on to model training and evaluation phases.

*3) Data class balancing*: In the data balancing stage, three different sampling techniques were applied to tackle class imbalance in the experiments: SMOTE, Random Undersampling, and a hybrid approach. SMOTE was used to generate synthetic instances for minority classes, Random Undersampling involved reducing instances in the majority class, and the hybrid approach combined both methods. The objective was to create balanced datasets to enhance model training. These sampling techniques were exclusively applied to the training set to ensure class balance for improved model performance.

*4) Data segmentation*: Data were segmented into overlapping windows, following a window size of one second with a 50% overlap. This facilitated the data's suitability for deep learning models.

*5) Training and hyperparameter optimization*: Deep learning models performed feature extraction automatically to identify relevant patterns in the segmented data.



Fig. 6.   Experiments pipeline.

The four models were trained using Bayesian Optimization to fine-tune hyperparameters for optimal model performance. The Keras Tuner library is utilized to search for the best hyperparameters.

The models are fine-tuned by adjusting several critical hyperparameters: the LSTM units, which determine the number of LSTM units in each LSTM layer, are explored within the range of 64 to 256, with a step size of 32. Similarly, the dense units, specifying the number of units in the dense layer, are considered within the range of 32 to 128, with a step size of 32. The batch size hyperparameter, significant for model training, is chosen from the options of 32, 64, or 128. The learning rate, influencing the optimizer's learning rate, is selected from values like 1e-3, 1e-4, or 1e-5. Furthermore, the dropout rate, responsible for controlling the dropout applied after each LSTM layer and the dense layer, varies from 0.1 to 0.5, with a step size of 0.1. The optimizer hyperparameter allows the choice of ADAM or RMSprop as the optimizer used to compile the model. The number of epochs in this experiments ranges from 50 to 100.This extensive exploration and fine-tuning of the models ultimately result in enhanced accuracy and robust performance for HAR tasks. All these hyperparameters are summarized in Table VI.

TABLE VI. HYPERPARAMETER RANGES FOR BAYESIAN OPTIMIZATION

| Hyperparameter | Search Space |
|---|---|
| Lstm Units | [32, 64, 96, 128] |
| Dense Units | [32, 64, 96, 128] |
| Dropout Rate | [0.1, 0.2, 0.3, 0.4, 0.5] |
| Optimizer | ['adam', 'rmsprop'] |
| Learning Rate | [1e-2, 1e-3, 1e-4] |
| Batch Size | [32, 64, 128] |
| Epochs | [50, 51, ..., 100] |

*6) Model evaluation*: To evaluate the models performance on the PAMPA2 dataset. The evaluation metrics were used including accuracy, precision, recall, F1-score and confusion matrix. These metrics were compared against those reported in previous literature studies conducted on the same dataset, enabling a comprehensive assessment of the proposed model's effectiveness and advancements in HAR.

Four experiments were conducted:

- Experiment 1: Train and test the four models on an imbalanced dataset.

- Experiment 2: Train and test the four models on the balanced dataset with SMOTE.

- Experiment 3: Train and test the four models on the balanced dataset with Random Undersampling.

- Experiment 4 : Train and test the four models on the balanced dataset with hybrid Sampling(SMOTE & Random Undersampling).

*D. Experiments Results*

*1) Experiment 1: Baseline*: In Experiment 1, the baseline was established to compare the effects of various data balancing techniques.

TABLE VII. THE SUMMARIZED HYPERPARAMETERS OF THE FOUR MODELS FOUND BY KERAS TUNER ON IMBALANCED DATA

| Hyper parameter | Vanilla LSTM | 2Stacked LSTM | 3 Stacked LSTM | CNN LSTM |
|---|---|---|---|---|
| Lstm Units | 32 | 64 | 96 | CNN units:128 Lstm units : 64 |
| Dense Units | 32 | 96 | 128 | - |
| Dropout Rate | 0.1 | 0.3 | 0.2 | 0.4 |
| Optimizer | RMSPROP | ADAM | ADAM | ADAM |
| Learning Rate | 0.001 | 0.001 | 0.001 | 0.001 |
| Batch Size | 32 | 32 | 128 | 128 |
| Epochs | 82 | 78 | 78 | 65 |

Subsequently, the four deep learning models were trained on the preprocessed imbalanced dataset. The optimization of hyperparameters for these models was carried out using Keras Tuner Bayesian optimization. The best hyperparameters of each model are summarized in Table VII.

Table VIII presents the results of Experiment 1, showcasing the performance metrics of the models, which include accuracy, precision, recall, and F1-score. These metrics were measured to establish a baseline for comparison.

TABLE VIII. RESULTS OF EXPERIMENT 1 ON IMBALANCED DATA

| Metrics | Vanilla LSTM | 2 Stacked LSTM | 3 Stacked LSTM | CNN LSTM |
|---|---|---|---|---|
| Accuracy | 0.9257 | **0.9531** | 0.9232 | 0.9308 |
| F1 Score | 0.9250 | **0.9529** | 0.9232 | 0.9297 |
| Precision | 0.9281 | **0.9536** | 0.9268 | 0.9341 |
| Recall | 0.9257 | **0.9531** | 0.9232 | 0.9308 |

Fig. 7 to Fig. 10 depicts the confusion matrices for the Vanilla LSTM model, 2-Stacked LSTM, 3-Stacked LSTM, and CNN-LSTM, respectively, on the imbalanced dataset.
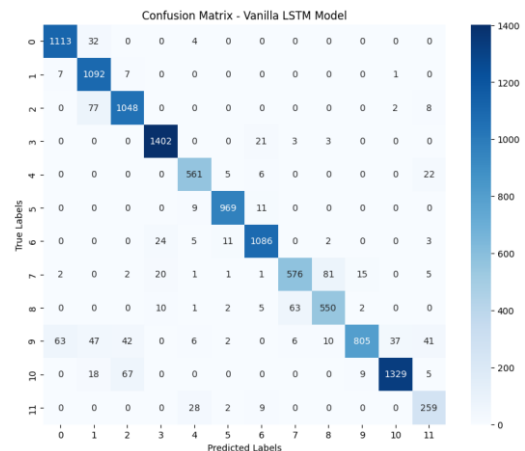


Fig. 7. Confusion matrix of vanilla LSTM model on imbalanced data.
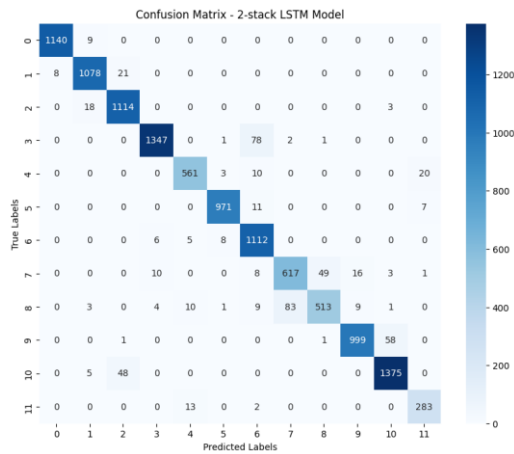
Fig. 8. Confusion matrix of 2 stacked LSTM model on imbalanced data.
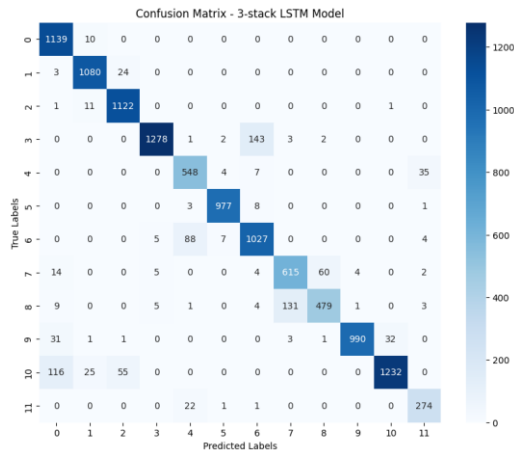


Fig. 9. Confusion matrix of 3 stacked LSTM model on imbalanced data.
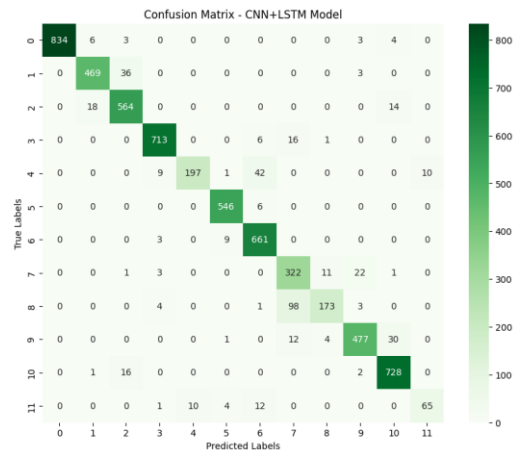


Fig. 10. Confusion matrix of CNN LSTM model on imbalanced data.

*2) Experiment 2: Balancing data with SMOTE*: In this experiment, the evaluation of model performance was conducted when trained on a dataset balanced using the Synthetic Minority Over-sampling Technique (SMOTE). The four models underwent training on the SMOTE-balanced dataset, and the search for the best hyperparameters for each

model was facilitated by Keras Tuner, as shown in Table VIII .

Performance metrics achieved in this experiment were observed and reported in Table IX, with a comparison to those from Experiment 1. Fig. 11 to Fig. 14 depicts the confusion matrices for the Vanilla LSTM model, 2-Stacked LSTM, 3-Stacked LSTM, and CNN-LSTM, respectively, on the balanced data with SMOTE (see Table X).

TABLE IX. THE SUMMARIZED HYPERPARAMETERS OF THE FOUR MODELS FOUND BY KERAS TUNER ON BALANCED DATA WITH SMOTE

| Hyper parameter | Vanilla LSTM | 2 Stacked LSTM | 3 Stacked LSTM | CNN LSTM |
|---|---|---|---|---|
| LSTM Units | 96 | 96 | 64 | CNN UNITS:128 LSTM UNITS:32 |
| Dense Units | 64 | 32 | 128 | 32 |
| Dropout Rate | 0.1 | 0.4 | 0.4 | 0.3 |
| Optimizer | RMSPROP | ADAM | RMSPROP | ADAM |
| Learning Rate | 0.01 | 0.001 | 0.01 | 0.001 |
| Batch Size | 32 | 32 | 32 | 64 |
| Epochs | 77 | 91 | 58 | 94 |
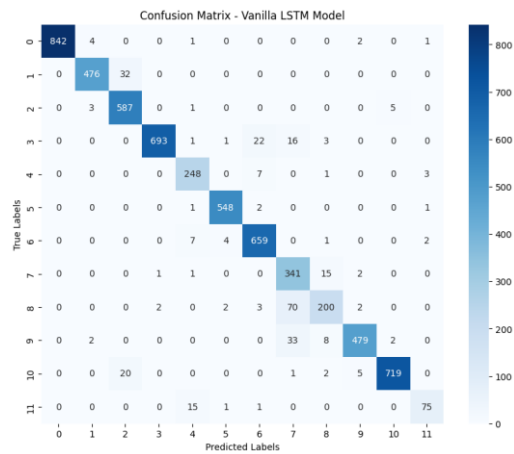


Fig. 11. Confusion matrix of vanilla LSTM on balanced data with SMOTE.
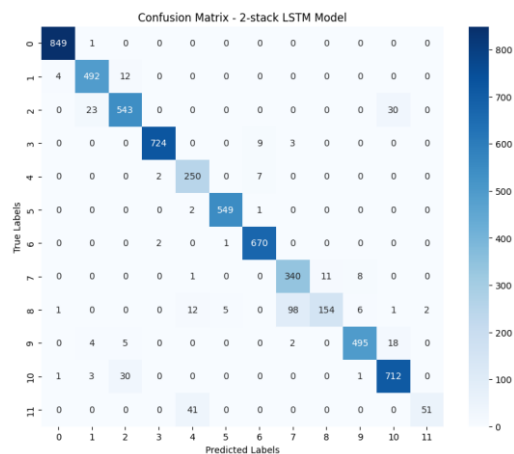


Fig. 12. Confusion matrix of 2 stack LSTM on balanced data with SMOTE.
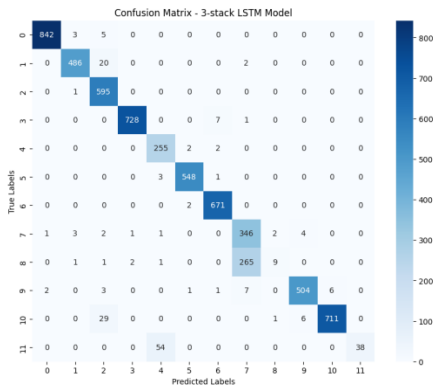
Fig. 13. Confusion matrix of 3 stacked LSTM on balanced data with SMOTE.
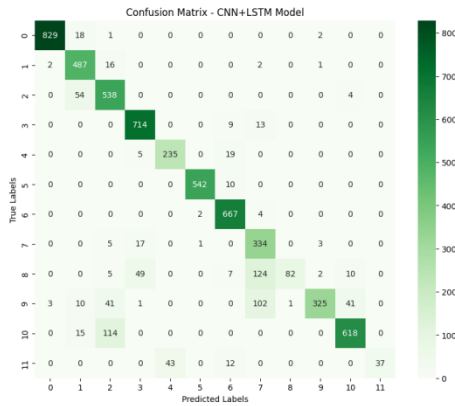


Fig. 14. Confusion matrix of CNN LSTM on balanced data with SMOTE.

*3) Experiment 3: Random undersampling*: Experiment 3 entailed the assessment of the models' performance when trained on a dataset balanced through Random Undersampling. The four models underwent training on the randomly undersampled Training set. The search for the best hyperparameters for each model was conducted using Keras Tuner, as indicated in Table XI and Table XII shows the Experiment 3on balanced data with random undersampling.

Performance metrics achieved in this experiment were observed and reported in Table XIII, with a comparison to those from Experiment 1. Fig. 15 to Fig. 18 illustrate the confusion matrices for the Vanilla LSTM model, 2-Stacked LSTM, 3-Stacked LSTM, and CNN-LSTM, respectively, on the balanced data achieved through Random Undersampling.

*4) Experiment 4: Hybrid sampling*: In Experiment 4, the examination of the models' performance was carried out when trained on a dataset balanced using hybrid sampling, combining SMOTE and random undersampling. The four models underwent training on the hybrid-sampled dataset. The search for the best hyperparameters for each model was conducted using Keras Tuner, as indicated in Table XIII.

Performance metrics from this experiment were documented in Table XIV and compared with the results from Experiment 1. Fig. 19 to Fig. 22 illustrate the confusion matrices for the Vanilla LSTM model, 2-Stacked LSTM, 3-Stacked LSTM, and CNN-LSTM, respectively, on the balanced data achieved through hybrid Sampling.

TABLE X.  RESULTS OF EXPERIMENT 2 ON BALANCED DATA WITH SMOTE

|  | Imbalanced data | | | | Balanced data With Smote | | | |
|---|---|---|---|---|---|---|---|---|
|  | *Vanilla LSTM* | *2 Stacked LSTM* | *3 Stacked LSTM* | *CNN LSTM* | *Vanilla LSTM* | *2 Stacked LSTM* | *3 Stacked LSTM* | *CNN LSTM* |
| **Accuracy** | 0.9257 | 0.9531 | 0.9232 | 0.9308 | **0.9499** | 0.9438 | **0.9282** | 0.8756 |
| **F1 Score** | 0.9250 | 0.9529 | 0.9232 | 0.9297 | **0.9503** | 0.9415 | **0.9129** | 0.8687 |
| **Precision** | 0.9281 | 0.9536 | 0.9268 | 0.9341 | **0.9537** | 0.9470 | **0.9386** | 0.8975 |
| **Recall** | 0.9257 | 0.9531 | 0.9232 | 0.9308 | **0.9499** | 0.9438 | **0.9282** | 0.8756 |

TABLE XI.  THE SUMMARIZED HYPERPARAMETERS OF THE FOUR MODELS FOUND BY KERAS TUNER ON BALANCED DATA WITH RANDOM UNDERSAMPLING

| Hyper Parameters | Vanilla LSTM | 2 Stacked LSTM | 3 stacked LSTM | CNN LSTM |
|---|---|---|---|---|
| **Lstm Units** | 32 | 96 | 128 | CNN UNITS:128 LSTM UNITS:32 |
| **Dense Units** | 96 | 64 | 32 | -- |
| **Dropout Rate** | 0.2 | 0.2 | 0.3 | 0.2 |
| **Optimizer** | RMSPROP | RMSPROP | RMSPROP | RMSPROP |
| **Learning Rate** | 0.01 | 0.01 | 0.01 | 0.0001 |
| **Batch Size** | 64 | 64 | 128 | 64 |
| **Epochs** | 75 | 62 | 62 | 73 |

TABLE XII. RESULTS OF EXPERIMENT 3 ON BALANCED DATA WITH RANDOM UNDERSAMPLING

| | Imbalanced Data | | | | Balanced Data With Random Undersampling | | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| | *Vanilla LSTM* | *2 Stacked LSTM* | *3 Stacked LSTM* | *CNN LSTM* | *Vanilla LSTM* | *2 Stacked LSTM* | *3 Stacked LSTM* | *CNN LSTM* |
| **Accuracy** | **0.9257** | **0.9531** | **0.9232** | **0.9308** | 0.7295 | 0.6361 | 0.2953 | 0.3706 |
| **F1 Score** | **0.9250** | **0.9529** | **0.9232** | **0.9297** | 0.6946 | 0.6070 | 0.2132 | 0.3194 |
| **Precision** | **0.9281** | **0.9536** | **0.9268** | **0.9341** | 0.6812 | 0.6113 | 0.3058 | 0.3767 |
| **Recall** | **0.9257** | **0.9531** | **0.9232** | **0.9308** | 0.7295 | 0.6361 | 0.2953 | 0.3706 |
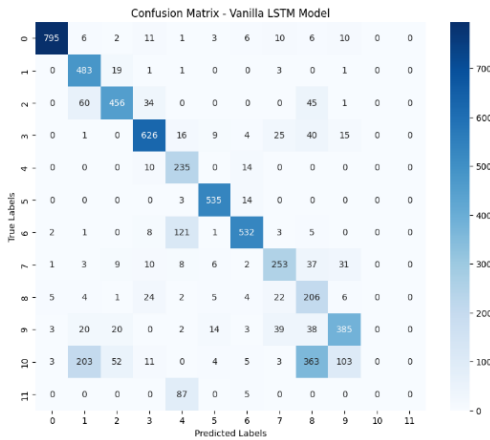


Fig. 15. Confusion matrix of Vanilla LSTM on balanced data with random undersampling.
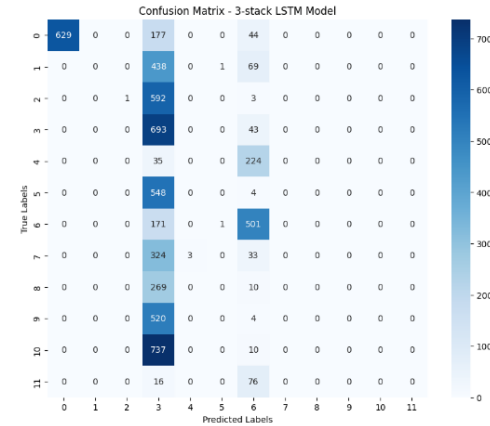


Fig. 17. Confusion matrix of 3 stacked LSTM on balanced data with random undersampling.
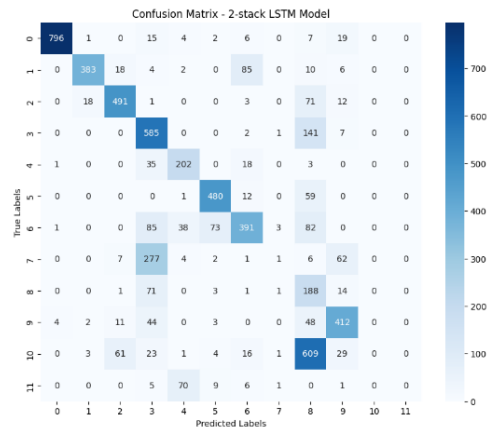


Fig. 16. Confusion matrix of 2 stacked LSTM on balanced data with random undersampling.
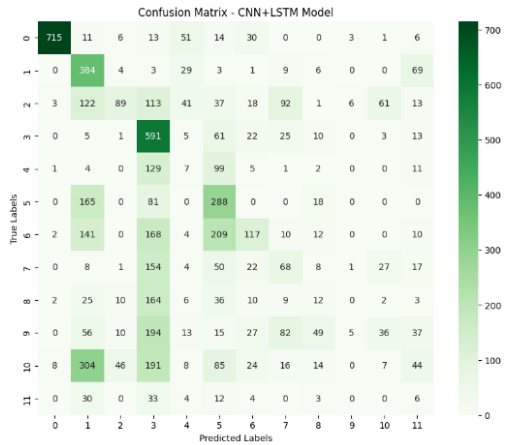


Fig. 18. Confusion matrix of CNN-LSTM on balanced data with random undersampling.

TABLE XIII. THE SUMMARIZED HYPERPARAMETERS OF THE FOUR MODELS FOUND BY KERAS TUNER ON BALANCED DATA WITH HYBRID SAMPLING

| Hyper parameter | Vanilla LSTM | 2 Stacked LSTM | 3 Stacked LSTM | CNN LSTM |
| --- | --- | --- | --- | --- |
| **Lstm Units** | 32 | 64 | 96 | CNN UNITS:96 LSTM UNITS:96 |
| **Dense Units** | 64 | 128 | 32 | -- |
| **Dropout Rate** | 0.3 | 0.3 | 0.2 | 0.3 |
| **Optimizer** | ADAM | RMSPROP | ADAM | ADAM |
| **Learning Rate** | 0.001 | 0.01 | 0.001 | 0.001 |
| **Batch Size** | 128 | 64 | 32 | 32 |
| **Epochs** | 56 | 78 | 81 | 93 |

TABLE XIV.   RESULTS OF EXPERIMENT 2 ON BALANCED DATA WITH HYBRID SAMPLING

| | Imbalanced data | | | | After hybrid undersampling | | | |
|---|---|---|---|---|---|---|---|---|
| | *Vanilla LSTM* | *2 Stacked LSTM* | *3 Stacked LSTM* | *CNN LSTM* | *Vanilla LSTM* | *2 Stacked LSTM* | *3 Stacked LSTM* | *CNN LSTM* |
| **Accuracy** | 0.9257 | 0.9531 | 0.9232 | 0.9308 | **0.9821** | **0.9755** | **0.9828** | **0.9351** |
| **F1 Score** | 0.9250 | 0.9529 | 0.9232 | 0.9297 | **0.9821** | **0.9752** | **0.9828** | **0.9342** |
| **Precision** | 0.9281 | 0.9536 | 0.9268 | 0.9341 | **0.9822** | **0.9764** | **0.9828** | **0.9350** |
| **Recall** | 0.9257 | 0.9531 | 0.9232 | 0.9308 | **0.9822** | **0.9755** | **0.9828** | **0.9351** |
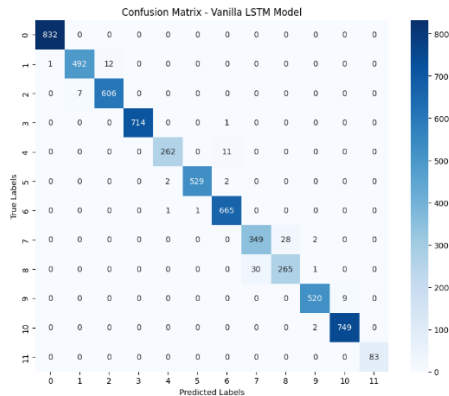


Fig. 19.  Confusion matrix of Vanilla LSTM on balanced data with hybrid sampling.
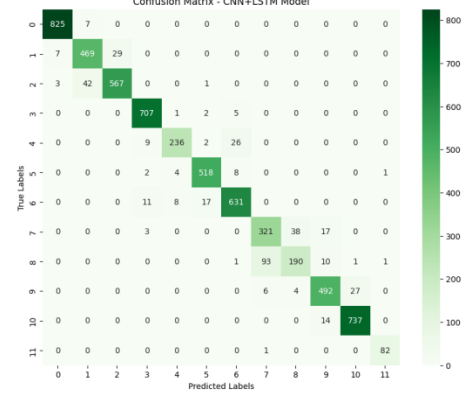


Fig. 22.  Confusion matrix of CNN-LSTM on balanced data with hybrid sampling.
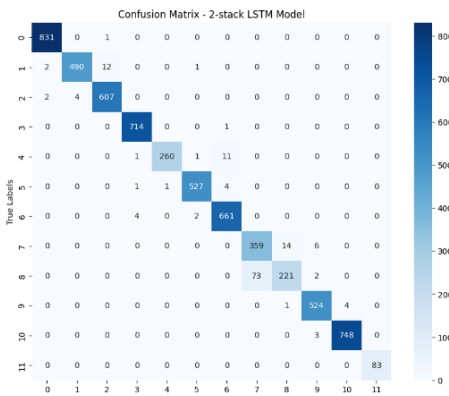


Fig. 20.  Confusion matrix of 2 stacked LSTM on balanced data with hybrid sampling.
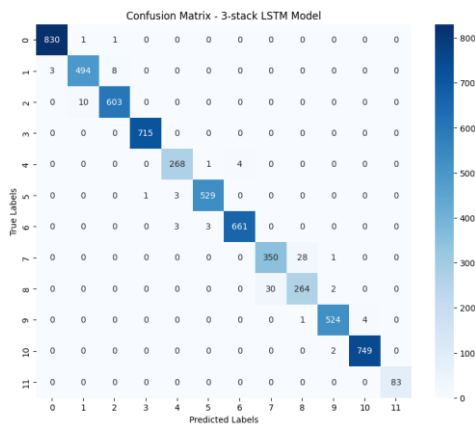
*E.  Comparative Results Analysis*

In this research paper, a comparative study was conducted employing four distinct deep learning models: Vanilla LSTM, 2 Stacked LSTM, 3 Stacked LSTM, and hybrid CNN-LSTM. The study aimed to address the challenge of class imbalance in Human Activity Recognition (HAR) through the utilization of three sampling techniques: SMOTE, Random Undersampling, and a novel Hybrid Sampling approach. The performance of these models was evaluated based on key metrics, including accuracy, F1 score, precision, and recall.

Accuracy Comparison of Deep Learning Models on Different Sampling Techniques (illustrated in Fig. 23):

- For models trained on imbalanced data, the 2 Stacked LSTM model exhibited the highest accuracy, achieving 0.9531. It was closely followed by the Vanilla LSTM model with an accuracy of 0.9257.

- When using SMOTE to balance the data, the Vanilla LSTM model performed remarkably well, with an accuracy of 0.9499. The 2 Stacked LSTM also showed strong performance with an accuracy of 0.9438.

- For Hybrid Sampling, the models reached even higher accuracy. The 2 Stacked LSTM achieved an accuracy of 0.9755, and the Vanilla LSTM excelled further with an impressive accuracy of 0.9821. The 3 Stacked LSTM model with Hybrid Sampling exhibited the most remarkable performance, achieving an accuracy of 0.9828.

F1-score Comparison of Deep Learning Models on Different Sampling Techniques (see Fig. 24):

- In terms of F1 score, similar trends were observed. The 2 Stacked LSTM model performed exceptionally well



Fig. 21.  Confusion matrix of 3 stacked LSTM on balanced data with hybrid sampling.

across all sampling techniques, reaching an F1 score of 0.9529 for imbalanced data and 0.9415 for data balanced with SMOTE.

- The models with Hybrid Sampling outperformed the others in F1 score. The 2 Stacked LSTM model achieved an F1 score of 0.9752, and the Vanilla LSTM excelled with an impressive F1 score of 0.9821. The 3 Stacked LSTM model with Hybrid Sampling exhibited the most remarkable performance, with an F1 score of 0.9828.

Precision Comparison of Deep Learning Models on Different Sampling Techniques (see Fig. 25):

- Precision results followed a similar pattern. The 2 Stacked LSTM model consistently showed high precision across all sampling techniques, with values ranging from 0.9536 to 0.9470.

- When using Hybrid Sampling, precision levels were remarkably high, with the models achieving precision values ranging from 0.9764 to 0.9537.

- The 3 Stacked LSTM model with Hybrid Sampling exhibited the most exceptional performance, with a precision of 0.9828.

Recall Comparison of Deep Learning Models on Different Sampling Techniques (see Fig. 26):

- Recall rates were also in line with accuracy and F1 score trends. The 2 Stacked LSTM model exhibited high recall, especially with Hybrid Sampling, where it reached a recall rate of 0.9755.

- The Vanilla LSTM model also performed well, achieving recall rates ranging from 0.9438 to 0.9499.

- The 3 Stacked LSTM model with Hybrid Sampling showed the most impressive result, with a Recall of 0.9828.

In summary, this study conclusively demonstrates the efficacy of hybrid sampling techniques in effectively addressing class imbalance challenges in HAR. The proposed models consistently achieve good results, especially the 3 Stacked LSTM, surpassing other models in terms of accuracy, precision, recall, and F1 scores. This underscores the crucial importance of balancing data for better-performing deep models. The comparative plots in Fig. 23 to Fig. 26 provide a visual representation of these findings.
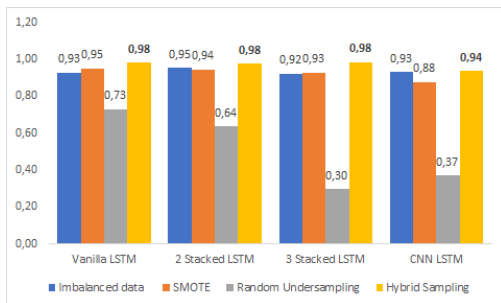


Fig. 23. Accuracy comparison of deep learning models on different sampling techniques.
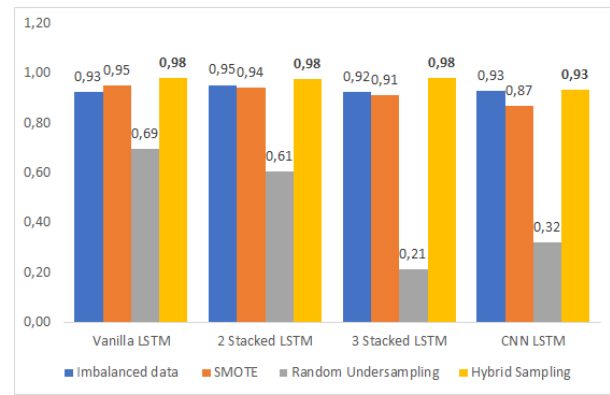


Fig. 24. F1 score comparison of deep learning models on different sampling techniques.
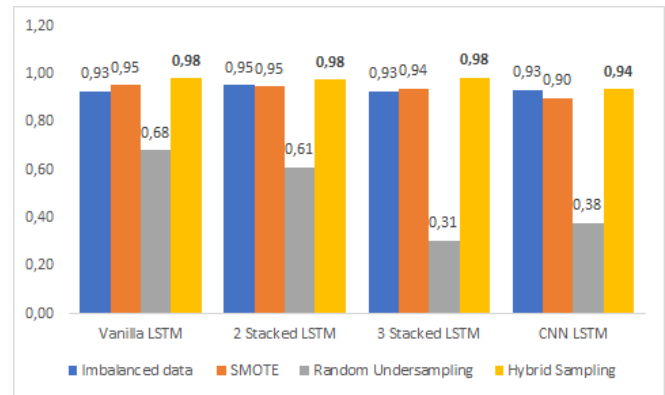


Fig. 25. Precision comparison of deep learning models on different sampling techniques.
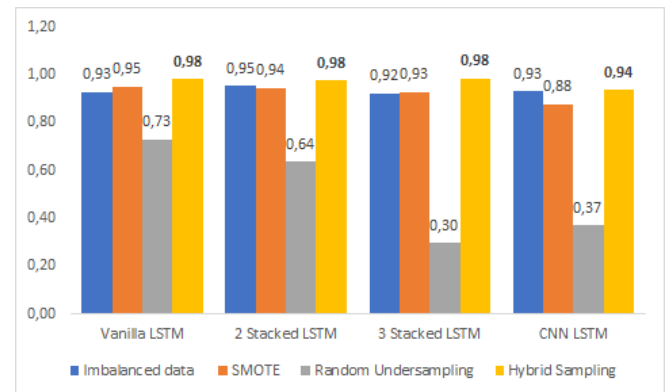


Fig. 26. Recall comparison of deep learning models on different sampling techniques.

Comparison with Previous Studies:

Previous research has extensively explored diverse deep-learning models for Human Activity Recognition (HAR) using the PAMPA2 dataset. As demonstrated in Table XV, these prior studies have yielded impressive outcomes. In 2022, an exemplary convLSTM Autoencoder (AE) model exhibited remarkable accuracy, recording a value of 0.9433, along with an F1 score of 0.9446 [4]. Similarly, in 2023, a Bi-LSTM model demonstrated commendable performance, achieving a high accuracy of 0.9341 and an F1 score of 0.9341, complemented by notable precision and recall values [17].

TABLE XV.    COMPARISON WITH PREVIOUS WORKS

| Study | year | Dataset | Classification method | Accuracy | F1 score | Precision | Recall |
|---|---|---|---|---|---|---|---|
| [15] | 2020 | PAMAP2 | LSTM | 0.8580 | 0.8534 | 0.8651 | 0.8467 |
| [15] | 2020 | PAMAP2 | LSTM | 0.8580 | 0.8534 | 0.8651 | 0.8467 |
| [16] | 2022 | PAMAP2 | LSTM | 0.8920 | 0.8949 | 0.8969 | 0.8928 |
| [4] | 2022 | PAMAP2 | convLSTM AE | **0.9433** | **0.9446** | - | - |
| [18] | 2022 | PAMAP2 | CNN-BiLSTM | 0.9429 | **-** | - | - |
| [16] | 2022 | PAMAP2 | LSTM | 0.8920 | 0.8949 | 0.8969 | 0.8928 |
| [18] | 2022 | PAMAP2 | CNN-BiLSTM | 0.9429 | **-** | - | - |
| [7] | 2022 | PAMAP2 | MLP with SMOTE | -- | 0.7473 | 0.7769 | 0.7493 |
| [17] | 2023 | PAMAP2 | Bi-LSTM | 0.9341 | 0.9341 | 0.9341 | 0.9347 |
| This Study | 2023 | PAMAP2 | Vanilla LSTM  on imbalanced data | 0.9257 | 0.9250 | 0.9281 | 0.9257 |
| | **2023** | **PAMAP2** | **2 Stacked lstm  on imbalanced data** | **0.9531** | **0.9529** | **0.9536** | **0.9531** |
| | 2023 | PAMAP2 | 3 Stacked LSTM  on imbalanced data | 0.9232 | 0.9232 | 0.9268 | 0.9232 |
| | 2023 | PAMAP2 | CNN-LSTM  on imbalanced data | 0.9308 | 0.9297 | 0.9341 | 0.9308 |
| | **2023** | **PAMAP2** | **Vanilla LSTM  with  SMOTE** | **0.9499** | **0.9503** | **0.9537** | **0.9499** |
| | **2023** | **PAMAP2** | **2 Stacked LSTM with SMOTE** | **0.9438** | 0.9415 | **0.9470** | **0.9438** |
| | 2023 | PAMAP2 | 3 Stacked LSTM with  SMOTE | 0.9282 | 0.9129 | 0.9386 | 0.9282 |
| | 2023 | PAMAP2 | CNN-LSTM with SMOTE | 0.8756 | 0.8687 | 0.8975 | 0.8756 |
| | 2023 | PAMAP2 | Vanilla LSTM  with   Random Undersampling | 0.7295 | 0.6946 | 0.6812 | 0.7295 |
| | 2023 | PAMAP2 | 2 Stacked LSTM with  Random Undersampling | 0.6361 | 0.6070 | 0.6113 | 0.6361 |
| | 2023 | PAMAP2 | 3 Stacked LSTM with   Random Undersampling | 0.2953 | 0.2132 | 0.3058 | 0.2953 |
| | 2023 | PAMAP2 | CNN-LSTM with Random Undersampling | 0.3706 | 0.3194 | 0.3767 | 0.3706 |
| | 2023 | PAMAP2 | CNN-LSTM with Hybrid Sampling | 0.9351 | 0.9342 | 0.9350 | 0.9351 |
| | **2023** | **PAMAP2** | **2 Stacked LSTM with Hybrid Sampling** | **0.9755** | **0.9752** | **0.9764** | **0.9755** |
| | **2023** | **PAMAP2** | **Vanilla LSTM  with  Hybrid Sampling** | **0.9821** | **0.9821** | **0.9822** | **0.9822** |
| | **2023** | **PAMAP2** | **3 Stacked LSTM with  Hybrid Sampling** | **0.9828** | **0.9828** | **0.9828** | **0.9828** |

Finally, our study demonstrates the effectiveness of Hybrid Sampling techniques in addressing class imbalance in HAR, leading to higher accuracy, precision, recall, and F1 scores. These models consistently outperformed the best-performing models from previous research, underscoring their potential to significantly enhance the accuracy and reliability of HAR systems and demonstrating the importance of tackling the imbalanced data problem.

## V.  DISCUSSION

Prior studies such as [6], [24] have highlighted the lack of works that address and investigate the impact of the class imbalance problem in human activity recognition. This present study fills this gap by comparing three sampling approaches, SMOTE, Random Undersampling, and Hybrid sampling to reduce the class imbalance and substantially improve human activity recognition (HAR) performance.

In this section, a comprehensive discussion of the experimental findings and their implications for the field of HAR using deep learning models is presented. The consideration encompasses the following key aspects: the impact of class imbalance, the effectiveness of sampling techniques, and the significance of hyperparameter tuning.

*1) Hyperparameter tuning enhances model adaptability and performance*: In all the experiments, hyperparameter tuning was applied in each scenario, proving to be a highly beneficial approach. The optimization of hyperparameters for each experiment ensured that the deep learning models were tailored to perform optimally under specific conditions. This adaptability is crucial in real-world applications where data characteristics and sampling techniques may vary. Moreover, hyperparameter tuning significantly contributed to the fairness of this comparative analysis. It prevented any model from having an unfair advantage due to suboptimal hyperparameters, ensuring a more equitable evaluation of different sampling techniques.

Overall, the inclusion of hyperparameter tuning in this experimental design serves as a robust foundation for meaningful comparisons and insights into HAR.

*2) Addressing class imbalance with sampling techniques:* The experiments aimed to investigate the impact of different sampling techniques on the performance of deep learning models in HAR. To address this, four experiments were conducted, each involving variations in data preprocessing and

sampling, and each of them incorporated hyperparameter tuning.

The results clearly demonstrate the notable impact of sampling techniques on model performance, further enhanced by hyperparameter tuning.

In Experiment 2, following the application of SMOTE and Hyperparameter Tuning, substantial improvements in accuracy, F1 score, precision, and recall were observed across all models. This underscores the effectiveness of SMOTE in addressing the class imbalance issue, especially when combined with optimal hyperparameters. The balanced dataset led to enhanced recognition efficiency, with significant gains in accuracy and F1 score.

In Experiment 3, involving Random under-sampling and Hyperparameter Tuning, the models exhibited decreased performance compared to the baseline.

In Experiment 4, employing hybrid sampling and hyperparameter tuning, remarkable results were achieved. By combining the strengths of SMOTE and Random Undersampling with fine-tuned hyperparameters, high accuracy and F1 scores were achieved, surpassing the baseline. This confirms the potential of hybrid sampling as a powerful technique for enhancing model performance, especially when hyperparameters are tuned effectively.

Hybrid sampling demonstrates its effectiveness in balancing data by leveraging the strengths of both oversampling (SMOTE) and undersampling (Random Undersampling) techniques. It begins by oversampling the minority class, increasing its representation, and then follows with undersampling the majority class to reduce redundancy. This approach enhances model performance, mitigates overfitting, and ensures that deep learning models are exposed to a more representative and diverse distribution of data. Consequently, these factors contribute to improved generalization, enabling models to make more accurate predictions. It is the combination of these advantages that positions hybrid sampling as an outperforming technique compared to other sampling methods.

*3) Model performance and generalization*: The findings suggest that deep learning models trained on balanced datasets exhibit improved performance compared to those trained on imbalanced data. This result highlights the significance of addressing class imbalance in HAR applications. Furthermore, these models demonstrated robust generalization capabilities, indicating their potential for real-world deployment.

*4) Practical implications*: The practical implications of this research extend to various applications, including healthcare, fitness tracking, and human-computer interaction. By improving the accuracy and reliability of HAR systems through both sampling techniques and hyperparameter tuning, this work contributes to enhancing user experiences and promoting healthier lifestyles.

*5) Limitations and future work*: It's important to acknowledge the limitations of this study. The choice of datasets, model architectures, and hyperparameters may

impact the generalizability of the findings. Future research could explore additional datasets, and more complex model architectures, and further investigate hyperparameter tuning techniques. Additionally, the real-world deployment of HAR systems should consider challenges related to sensor placement, data privacy, and user variability.

In conclusion, this study emphasizes the critical role of both sampling techniques and hyperparameter tuning in improving the performance of deep learning models for HAR. SMOTE and hybrid sampling methods, when coupled with effective hyperparameter tuning, demonstrate their effectiveness in addressing class imbalance. The achievement of enhanced accuracy and F1 scores through these combined techniques paves the way for more reliable and efficient HAR systems with broader applications.

## VI. CONCLUSION

In this extensive study on Human Activity Recognition (HAR) using deep learning models and wearable sensor data, the goal was to enhance the accuracy and reliability of HAR systems, which are crucial in healthcare and sports analytics. The challenge of imbalanced datasets in HAR was addressed by exploring different sampling techniques: Synthetic Minority Over-sampling Technique (SMOTE), random undersampling, and hybrid sampling (a combination of SMOTE and random undersampling). These techniques were tested with various deep learning models, including Vanilla LSTM, 2 Stacked LSTM, 3 Stacked LSTM, and Hybrid CNN-LSTM. The findings showed significant improvements in model performance when using sampling techniques to balance the data. SMOTE and hybrid sampling were particularly effective in countering class imbalance, leading to notable enhancements in model accuracy, precision, recall, and the F1 score. The importance of hyperparameter tuning, involving adjustments to specific model settings, was also highlighted. By fine-tuning these parameters, even better model performance was achieved, emphasizing the critical connection between data preprocessing and parameter configuration. As wearable sensors become more prevalent, this research contributes to the creation of systems that can better understand and interpret human actions in various real-world scenarios. Future work will involve experiments with more diverse public datasets, the exploration of more complex deep learning models, and the investigation of additional sampling techniques to further advance the field of Human Activity Recognition

### REFERENCES

[1] S. S. Zhang et al., "Deep Learning in Human Activity Recognition withWearable Sensors: A Review on Advances," Sensors, vol. 22, no. 4, p. 1476, Feb. 2022, doi: 10.3390/s22041476.

[2] M. Gochoo, F. Alnajjar, T. H. Tan, and S. Khalid, "Towards privacy - preserved aging in place: A systematic review," Sensors, vol. 21, no. 9, p. 3082, Apr. 2021, doi: 10.3390/s21093082.

[3] A. Kristoffersson and M. Lindén, "A systematic review on the use of wearable body sensors for health monitoring: A qualitative synthesis," Sensors (Switzerland), vol. 20, no. 5, p. 1502, Mar. 2020, doi: 10.3390/s20051502.

[4] D. Thakur, S. Biswas, E. S. L. L. Ho, and S. Chattopadhyay, "ConvAE-LSTM: Convolutional Autoencoder Long Short-Term Memory Network

for Smartphone-Based Human Activity Recognition," IEEE Access, vol. 10, pp. 4137–4156, Jun. 2022, doi: 10.1109/ACCESS.2022.3140373.

[5] J. Yu, A. de Antonio, and E. Villalba-Mora, "Deep Learning (CNN, RNN) Applications for Smart Homes: A Systematic Review," Computers, vol. 11, no. 2, pp. 1–32, Feb. 2022, doi: 10.3390/computers11020026.

[6] H. Kaur, H. S. Pannu, and A. K. Malhi, "A systematic review on imbalanced data challenges in machine learning: Applications and solutions," ACM Comput. Surv., vol. 52, no. 4, 2019, doi: 10.1145/3343440.

[7] F. Alharbi, L. Ouarbya, and J. A. Ward, "Comparing Sampling Strategies for Tackling Imbalanced Data in Human Activity Recognition," Sensors, vol. 22, no. 4, pp. 1–20, 2022, doi: 10.3390/s22041373.

[8] D. Roggen et al., "Collecting complex activity datasets in highly rich networked sensor environments," INSS 2010 - 7th Int. Conf. Networked Sens. Syst., pp. 233–240, 2010, doi: 10.1109/INSS.2010.5573462.

[9] J. R. Kwapisz, G. M. Weiss, and S. A. Moore, "Activity Recognition using Cell Phone Accelerometers," 2010.

[10] A. A. A. Alani, G. Cosma, and A. Taherkhani, "Classifying Imbalanced Multi-modal Sensor Data for Human Activity Recognition in a Smart Home using Deep Learning," in Proceedings of the International Joint Conference on Neural Networks, 2020. doi: 10.1109/IJCNN48605.2020.9207697.

[11] A. Reiss and D. Stricker, "Creating and benchmarking a new dataset for physical activity monitoring," in ACM Int. Conf. Proceeding Ser, 2012.

[12] D. H. Jeong, S. E. Kim, W. H. Choi, and S. H. Ahn, "A Comparative Study on the Influence of Undersampling and Oversampling Techniques for the Classification of Physical Activities Using an Imbalanced Accelerometer Dataset," Healthc., vol. 10, no. 7, 2022, doi: 10.3390/healthcare10071255.

[13] R. A. Hamad, M. Kimura, and J. Lundström, "Efficacy of Imbalanced Data Handling Methods on Deep Learning for Smart Homes Environments," SN Comput. Sci., vol. 1, no. 4, pp. 1–10, 2020, doi: 10.1007/s42979-020-00211-1.

[14] A. A. Alani, G. Cosma, and A. Taherkhani, "Classifying Imbalanced Multi-modal Sensor Data for Human Activity Recognition in a Smart Home using Deep Learning," in Proceedings of the International Joint Conference on Neural Networks, 2020. doi: 10.1109/IJCNN48605.2020.9207697.

[15] S. Wan, L. Qi, X. Xu, C. Tong, and Z. Gu, "Deep Learning Models for Real-time Human Activity Recognition with Smartphones," Mob. Networks Appl., vol. 25, no. 2, pp. 743–755, Apr. 2020, doi: 10.1007/s11036-019-01445-x.

[16] Y. Xu and L. Zhao, "Inception-LSTM Human Motion Recognition with Channel Attention Mechanism," Comput. Math. Methods Med., vol. 2022, 2022, doi: 10.1155/2022/9173504.

[17] A. Tehrani, M. Yadollahzadeh-Tabari, A. Zehtab-Salmasi, and R. Enayatifar, "Wearable Sensor-Based Human Activity Recognition System Employing Bi-LSTM Algorithm," Comput. J., no. April, 2023, doi: 10.1093/comjnl/bxad035.

[18] S. K. Challa, A. Kumar, and V. B. Semwal, "A multibranch CNN-BiLSTM model for human activity recognition using wearable sensor data," Vis. Comput., vol. 38, no. 12, pp. 4095–4109, 2022, doi: 10.1007/s00371-021-02283-3.

[19] S. Hochreiter and J. Schmidhuber, "Long Short-Term Memory," Neural Comput., vol. 9, no. 8, pp. 1735–1780, Nov. 1997, doi: 10.1162/NECO.1997.9.8.1735.

[20] C. Liu, L. Zhang, Z. Liu, K. Liu, X. Li, and Y. Liu, "Lasagna: Towards deep hierarchical understanding and searching over mobile sensing data," Proc. Annu. Int. Conf. Mob. Comput. Networking, MOBICOM, vol. 0, no. 1, pp. 334–347, Oct. 2016, doi: 10.1145/2973750.2973752.

[21] S. Mekruksavanich and A. Jitpattanakul, "Lstm networks using smartphone data for sensor-based human activity recognition in smart homes," Sensors, vol. 21, no. 5, pp. 1–25, 2021, doi: 10.3390/s21051636.

[22] N. S. Khan and M. S. Ghani, A Survey of Deep Learning Based Models for Human Activity Recognition, vol. 120, no. 2. Springer US, 2021. doi: 10.1007/s11277-021-08525-w.

[23] "KerasTuner." https://keras.io/keras_tuner/ (accessed Jul. 23, 2023).

[24] K. Chen, D. Zhang, L. Yao, B. Guo, Z. Yu, and Y. Liu, "Deep learning for sensor-based human activity recognition: Overview, challenges, and opportunities," ACM Comput. Surv., vol. 54, no. 4, Jul. 2021, doi: 10.1145/3447744.

# APPENDIX A

TABLE A1: DATASET INSTANCES BEFORE AND AFTER APPLYING SAMPLING METHODS

| Activity ID | Class ID | # Instances in training set of the imbalanced data | # Instances in the testing set | # Instances training set After SMOTE | # Instances training set After Random Undersampling | # Instances training set After Hybrid Sampling |
|---|---|---|---|---|---|---|
| 1 | 0 | 100298 | 42633 | 100298 | 10889 | 1968 |
| 2 | 1 | 58380 | 25358 | 100298 | 10889 | 1160 |
| 3 | 2 | 70165 | 29808 | 100298 | 10889 | 1436 |
| 4 | 3 | 86117 | 36789 | 100298 | 10889 | 1723 |
| 5 | 4 | 30100 | 12950 | 100298 | 10889 | 599 |
| 6 | 5 | 63755 | 27585 | 100298 | 10889 | 1249 |
| 7 | 6 | 78154 | 33678 | 100298 | 10889 | 1546 |
| 12 | 7 | 41442 | 17872 | 100298 | 10889 | 849 |
| 13 | 8 | 32800 | 14030 | 100298 | 10889 | 661 |
| 16 | 9 | 60703 | 26256 | 100298 | 10889 | 1226 |
| 17 | 10 | 87885 | 37343 | 100298 | 10889 | 1774 |
| 24 | 11 | 10889 | 4564 | 100298 | 10889 | 221 |

# Design of an Advanced Distributed Adaptive Control for Multi-SMA Actuators

Belkacem Kada[*], Khalid A. Juhany, Ibraheem Al-Qadi, Mostefa Bourchak
Aerospace Engineering Department, King Abdulaziz University, Jeddah, KSA

*Abstract*—**Aerospace applications place high demands on designing Shape Memory Alloy (SMA) actuators, including accuracy, dependability, high-performance criteria, and cooperative activation. Because of their portability, durability, and performance under extreme conditions, SMAs have found a home in the aerospace industry as single and array actuators. This paper presents the development of a control scheme for thermally activating rotary SMA actuators as single and cooperative actuators. The control scheme is a hybrid adaptive robust control abbreviated as HARC. The immersion and invariance adaptive (I&I adaptive) and L2-gain control frameworks are utilized in developing the HARC approach. To create stable transient responses despite parametric and non-parametric errors, recursive backstepping is utilized for asymptotic stability. At the same time, L2-gain control is applied to ensure the global stability of the transient closed-loop system. Both techniques are used in conjunction with one another. In contrast to the conventional I&I, the robust control law can be developed without needing a target system or the solution of PDEs to satisfy the I&I condition. The parametric uncertainty is estimated with the help of an adaptive rule, and the non-parametric uncertainty brought on by the phase change of the SMA material and modeling mistakes is accounted for with the help of asymptotic nonlinear functions. The designed HARC is then extended to cover the actuation of multi-SMA or array actuators to respond to the increasing demand for cooperative controllers using distributed control protocols. It has been demonstrated through simulation testing on a rotational NiTi SMA actuator that the suggested control approach is both practical and resilient.**

*Keywords—Adaptive backstepping; hysteresis; I&I control; L2-gain control; rotary actuator; shape memory alloy*

## I. INTRODUCTION

Shape memory alloy (SMA) materials are promising materials for enhanced aircraft actuation because to their excellent physical and thermomechanical properties. SMA materials outperform other materials in terms of shape memory effect (SME) and superelasticity. The capacity of distorted SMA to regain its original shape following heating is referred to as superelasticity. Because of their superior performance qualities, SMA actuators can be employed in place of more traditional actuation solutions like solenoids, motors, thermometers, and even vacuum and pneumatic systems. SMA actuators have excellent control characteristics such as rapid response time, oscillation damping, and low power consumption. SMA actuators are of tremendous interest and usage in many cutting-edge industries, such as aerospace, automotive, information technology, and biomedical engineering [1-3]. Additionally, SMA actuators are highly effective at absorbing and dissipating mechanical energy. They can be used in numerous forms, including wires, springs, and strips. Typically, the actuation frequency of SMA actuators is much lower than that of conventional actuators such as DC/AC motors and hydraulic systems.

SMA twist or rotational actuators are a feasible solution for traditional step motors. They can be used to make helical torsion springs, twisted wires, twisted strips, thin-sheet torsional actuators, and antagonistic multiple-wire designs [4,5]. Applications for SMA torsional actuators include self-reconfigurable and modular robots, surgical instruments, and transformable wings [6-8]. SMA thermal activation via Joule heating with an electrical current is an efficient way for optimizing the effect of shape memory [9,10]. Understanding the heat activation and heat transport mechanisms of shape memory alloys is essential for employing them creatively and increasing their possible uses. However, the solid-state phase transformation and its accompanying physical phenomena, such as hysteresis, make regulating SMA-based actuators a difficult task.

To address the problem of SMA twist actuator control, various nonlinear control approaches were used. Sliding mode control (SMC) has been used in a variety of topologies to address nonlinear dynamics and hysteresis in SMA materials, as well as parameter uncertainties in system modeling. A wide range of SMC-based rotary SMA controllers have been designed and implemented for a wide range of engineering systems, including morphing airplanes [11], artificial muscles inspired by the human arm [12], multi-rod bars for flexible robotic arms [13], and flexible needles for clinical applications [14]. Despite applying various strategies, such as the saturation boundary layer function, the SMC-based controllers displayed control input chattering, which is damaging to the actuation systems. The challenges of SMA modeling and control have been overcome, for example, by employing fuzzy logic control (FLC) and artificial neural networks (AINN). Several studies on FLC and ANN for SMA have been published [15-20]. However, both FLC and ANN implementation necessitate sophisticated and time-consuming techniques.

Adaptive backstepping control (ABC) is a powerful robust control approach that is commonly used in the control design of nonlinear, dynamically unpredictable, and nonsmoothed systems. ABC is a promising new method for industrial applications, particularly in electrical, medical, and aerospace systems. Few studies have been conducted to address the problem of SMA hysteresis control using nonlinear adaptive backstepping control. Recently, [21] addressed the problem of hysteresis in control systems by employing a unique hysteresis

model and an ABC to assure stable and accurate control. In [22], authors used ABC to design a control system for a soft robotic muscle inspired by biology. The authors demonstrated that ABC outperforms adaptive sliding mode control regarding time-domain response performance. This paper presents a new hybrid adaptive robust control (HARC) method to thermally activate SMA rotary actuators in the presence of parametric and non-parametric uncertainties. The technique combines I&I-adaptive control with $L_2$-gain control. A Lyapunov-based analysis of the controller's stability is presented. The proposed controller can provide robust and rapid tracking of the desired system response despite its asymptotic convergence. The following is the outline for the paper. In Section II, the thermomechanical modeling of a rotary SMA actuator is presented along with the control objective of this paper. Section III presents the design of a nonlinear backstepping controller and an adaptive parameter law. Additionally, a stability analysis is investigated. Section IV presents numerical results, while Section V provides a conclusion and future perspectives.

## II. MATHEMATICAL MODELING OF A ROTARY SMA ACTUATOR AND CONTROL OBJECTIVE

In this study, the angular position response of a rotary SMA actuator is controlled by the thermally induced shape-memory effect (SME) under electrical current input where the electrical power is converted to heat. Typically, this mechanism is used to control the SMA actuator. Under the influence of heat, the SMA actuator phase transitions from martensite to austenite and then back to martensite upon cooling. Fig. 1 shows some aerospace applications of SMA actuators.



a)



b)
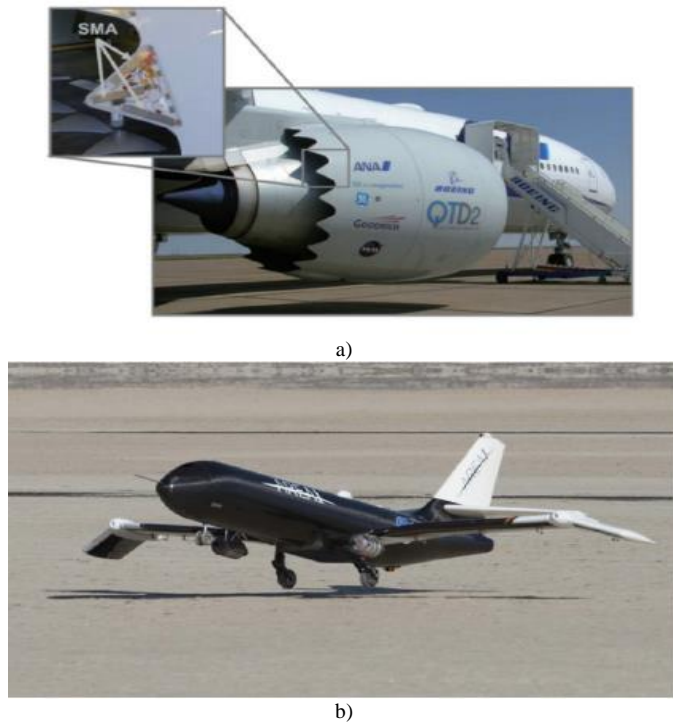
Fig. 1. SMA actuators applied in aerospace control i: a) SMA actuator for Boeing 777-300ER airplane engines [24]; b) SMA actuator for torque control of the outboard wing section.

A heating or cooling process governs the phase transformation of SMAs from martensite to austenite and vice versa. During the heating process, unloaded martensite begins to transform into austenite at the austenitic start temperature $A_s$ with a martensite volume fraction $\xi = 1$. The transformation continues until the austenitic transition temperature $A_f$ and $\xi = 0$ are reached. The hysteresis loop depicted in Fig. 1(b) explains the irreversible nature of the crystalline structure change during thermally induced SME.

### A. Thermomechanical Modeling

Consider an SMA model wire with a small diameter and a lumped capacitance, where the internal thermal gradient is small and the latent heat effects are negligible. The following lumped-capacitance thermal and Liang-Brinson phenomenological model was found to be adequate for this study [24].

$$\begin{cases} mC_p\dot{T} + hA_c[T - T_0] = R\,u \\ \dot{\sigma} = E\dot{\epsilon} + \Omega\dot{\xi} + \Theta\dot{T} \end{cases} \quad (1)$$

where, $\sigma$, $\epsilon$, $T$ denote the stress, strain, and temperature states; $m$, $C_p$, $h$, $A_c$, $R$ denote the actuator's mass, specific heat, convection heat transfer coefficient, convection area, and resistor, respectively; $\Omega$ denotes the phase transformation, $T_{amb}$ is the ambient temperature and $u = i_c^2$ denotes the control input where $i_c$ is the electrical current. The elastic deformation $\epsilon$ is given by

$$\epsilon = (l - l_0 - r\theta)/l_0 \quad (2)$$

where, $l_0$ is the initial length of the SMA actuator. The lumped-capacitance thermal model exhibits mathematically simple behavior and conforms to Newton's law of cooling.

$$T_{cool}(t) = T_0 + (T_w - T_0)e^{-\lambda t} \quad (3)$$

where, $T_0$ is the ambient temperature, $T_w$ is the initial temperature of the wire, and $\lambda = hA_c/mC_p$. The stress-strain model is a macro-mechanical or phenomenological constitutive law developed by Tanaka and updated by Liang and Brinson [25]. The model considers both thermomechanical and phase transformations. In Liang-Brinson model, the phase transformation volume fraction is modified to include the effect of complex loadings using cosine function rather than the exponential function used in Tanaka model.

### B. Enhanced SME Model

We use the Elahinia-Ahmadian phase transformation model to predict the SMA behavior under complex fast stress and temperature loadings, which is the case for most rotary actuators. Experiments have demonstrated that the modified model can predict SMA behavior under complex loading conditions [26, 27]. The martensite volume fraction is calculated using the following equation during the reverse transformation of martensite to austenite by heating.

$$\xi = \frac{\xi_M}{2}\{cos[a_A(T - A_s) + b_A\sigma] + 1\} \quad (4)$$

The reverse phase transformation occurs under the following heating and unloading conditions.

$$\begin{cases} A_s + \frac{\sigma}{C_A} < T < A_f + \frac{\sigma}{C_A} \\ \dot{T} - \frac{\dot{\sigma}}{C_A} > 0 \end{cases} \quad (5)$$

Similar conditions were developed for the modified austenite to martensite phase transformation using cosine equation. The martensite volume fraction is computed as follows:

$$\xi = \frac{1-\xi_A}{2} cos[a_M(T - M_f) + b_M\sigma] + \frac{1+\xi_A}{2} \quad (6)$$

with

$$\begin{cases} M_f + \frac{\sigma}{C_M} < T < A_s + \frac{\sigma}{C_M} \\ \dot{T} - \frac{\dot{\sigma}}{C_M} < 0 \end{cases} \quad (7)$$

In this formulation $C_M$ and $C_A$ are material properties which describe the relationship between temperature and critical stress to induce transformation, and the parameters $a_M$ and $a_T$ are defined by

$$a_M = \frac{\pi}{M_s - M_f}, \quad a_A = \frac{\pi}{A_f - A_s} \quad (8)$$

### C. Kinematic and Dynamic Modeling

The SMA actuator model is a bias-type actuator whose general kinematics and dynamics equations are given as follows:

$$\begin{cases} \dot{\theta} = \omega \\ J\dot{\omega} + b(\theta)\omega + k\theta = \tau_s(\sigma) \end{cases} \quad (9)$$

where, $\theta, \omega, J, b, k$ are the actuator's angular position, angular velocity, effective inertia, damping, and stiffness, respectively; $\tau, \sigma$ denote the control effort and the Piola-Kirchhoff's stress. The input torque $\tau_s(\sigma)$ is supposed to be a linear function of the mechanical stress $\sigma$

$$\tau(\sigma) = Ar\sigma \quad (10)$$

### D. Control Objective

The control objective is to guarantee that the transient trajectories of the angular position, angular speed, the temperature are globally bound and converge to a new equilibrium despite hysteresis. We introduce, in systems (1) and (9), the new states $x_1 = \theta, x_2 = \omega, x_3 = T$ with an initial steady-state operating equilibrium defined as $[\theta_0 \quad \omega_0 \quad T_0]^T$

$$\begin{cases} \dot{x}_1 = x_2 \\ \dot{x}_2 = -a_1 x_1 - \beta x_2 + a_2 x_3 + f_1(\xi, T) \\ \dot{x}_3 = -b_1(x_3 - T_0) + b_2 u + f_2(\xi, T) \end{cases} \quad (11)$$

with

$$\begin{cases} a_1 = k/J, \ a_2 = \alpha Ar/J, \ \beta = b/J, \\ b_1 = hA_c/(mC_p), \ b_2 = R/(mC_p) \end{cases}$$

The model in (11) is a nonlinear dynamic model where $\beta$ denotes the uncertainty in the damping properties of the actuator and $f_1(\xi)$ and $f_2(\dot{\xi})$ are uncertain bounded functions denoting the nonlinear hysteretic terms. The upper limits $f_1(\xi)$ and $f_2(\dot{\xi})$ satisfy

$$|f_i| \le l \in \mathbb{R}^+ \quad (12)$$

For simplicity, in the following $f_1(\xi)$ and $f_2(\xi)$ are substituted by $f_1$ and $f_2$. The control input $u$ in (11) is designed to provide a robust and adaptive control input to the thermal actuation system of the SMA actuator. The adaptive law $\hat{u} = u(x, \hat{\beta})$, where $\hat{\beta}$ denotes the estimator of $\beta$ provided by a proper adaptive law, is designed to compensate for parametric and non-parametric uncertainties. The robustness control component is designed using dissipation theory for which an energy storage function $V(x(t))$ is selected to guarantee the following condition.

$$V(x(t)) - V(x(0)) = \int_0^T L(f(\xi))dt \quad (13)$$

where $f = [f_1 \ f_2]^T$ and $L$ is an energy supply function. The parameter adaptive law is designed as follows.

$$\dot{\hat{\beta}} = \Phi(x, \hat{\beta}) \quad (14)$$

In absence of phase transformation, the control input $u(x, \hat{\beta})$ with the parameter adaptive law (14) guarantee the global asymptotic stability of the closed loop (11). For the case $f_i \ne 0 \ (i = 1,2)$, a global asymptotic stability is provided by the control law $u(x, \hat{\beta})$ under L₂-gain control bound.

### III. ADAPTIVE ROBUST SMA CONTROLLER DESIGN

#### A. Parameter Adaptive Law

The parameter adaptive law is designed to alleviate the influences of nonlinear parameter uncertainties. To construct the adaptive law (14), a parameter estimation error is defined as follows:

$$\varphi = \hat{\beta} - \beta + \rho(x_1, x_2) \quad (15)$$

where, $\rho(x_1, x_2)$ can be chosen as function of the actuator's motion states and be designed such that $\lim_{t\to\infty} \varphi = 0$. For simplicity $\rho(x_1, x_2)$ is denoted by $\rho$. The time derivative of expression (15) along the trajectories (11) gives

$$\dot{\varphi} = \dot{\hat{\beta}} + \frac{\partial \rho}{\partial x_1}\dot{x}_1 + \frac{\partial \rho}{\partial x_2}\dot{x}_2 \quad (16)$$

Using the dynamic model in (11), the time derivative $\dot{\varphi}$ is written as follows

$$\dot{\varphi} = \dot{\hat{\beta}} + \frac{\partial \rho}{\partial x_1}x_2 + \frac{\partial \rho}{\partial x_2}(-a_1 x_1 - \beta x_2 + a_2 x_3 + f_1) \quad (17)$$

Consider the case of $f_1 = 0$ and suppose that $\varphi$ is asymptotically convergent function with $\lim_{t\to\infty} \varphi = 0$, the estimator $\hat{\beta}$ can be chosen as

$$\dot{\hat{\beta}} = -\frac{\partial \rho}{\partial x_1}x_2 - \frac{\partial \rho}{\partial x_2}(-a_1 x_1 - (\hat{\beta} + \rho)x_2 + a_2 x_3) \quad (18)$$

which yields to

$$\dot{\varphi} = -\frac{\partial \rho}{\partial x_2}(\varphi x_2 - f_1) \quad (19)$$

## B. Robust Control Law Design

To design a robust SMA controller, we define for the dynamic system the following tracking errors

$$\begin{cases} e_1 = x_1 - x_1^* \\ e_2 = x_2 - x_2^* \end{cases} \tag{20}$$

where, $x_1^*, x_2^*$ are of class $C^{(0)}$ and define the desired states that serve as virtual control inputs to the first and second equations of model in (11).

Step 1: Angular position subdynamics stabilization

From the first equation in system in (20), the dynamic of $e_1$ is obtained as

$$\dot{e}_1 = x_2 = e_2 + x_2^* \tag{21}$$

With $e_2 = 0$, the system in (21) is stable under the following virtual control law.

$$x_2^* = -k_1 x_1 \tag{22}$$

Step 2: Angular velocity subdynamics stabilization.

$$\dot{e}_2 = -a_1 x_1 - \beta x_2 + a_2 x_3 + f_1 + k_1 x_2 \tag{23}$$

For the effect of the phase transformation on the actuator dynamics, we propose the following dissipation function.

$$L_1 = \frac{d}{dt} \sum_{i=1}^{2} \left( \frac{1}{2} e_i^2 \right) + \frac{1}{2} (\|\boldsymbol{h}\|^2 - \mu^2 f_1^2) \tag{24}$$

where $\boldsymbol{h} = [p_1 x_1 \quad p_2 x_2]^T$ is the output vector and $\mu \in \mathbb{R}^+$. Substituting (16) and (18) into (19) gives

$$L_1 = [e_1 x_2 + e_2(-a_1 x_1 - \beta x_2 + a_2 x_3 + f_1 + k_1 x_2)] + \frac{1}{2}(p_1^2 x_1^2 + p_2^2 x_2^2 - \mu^2 f_1^2) \tag{25}$$

One can write (23) as follows:

$$L_1 = -\alpha_1 e_1^{2.} - \frac{1}{2} \left( \mu f_1 - \frac{e_2}{\mu} \right)^2 - \frac{1}{4} \mu^2 f_1^2 + e_2 [\alpha_2 x_1 + (-\beta + \alpha_3) x_2 + a_2 x_3] \tag{26}$$

with

$$\alpha_1 = k_1 - \frac{1}{2} p_2^2 k_1^2 - \frac{1}{2} p_1^2, \quad \alpha_2 = k_1 \left( \frac{1}{\mu^2} - \frac{1}{2} p_2^2 \right) + 1 - a_1,$$
$$\alpha_3 = k_1 + \frac{1}{2} p_2^2 + \frac{1}{\mu^2}$$

To satisfy the dissipation condition for the function $f_1$, a virtual control $x_3^*$ is chosen as follows

$$x_3^* = \frac{-\alpha_2 x_1 - (\hat{\beta} + \rho + \alpha_3) x_2}{a_2} \tag{27}$$

where $\hat{\beta}$ is the estimation of $\beta$ to be provided by the adaptive law and $\rho$ is a smooth function to be designed later. Substituting (26) into (27), the function $F_1$ becomes

$$L_1 = -\alpha_1 e_1^{2.} - \frac{1}{2} \left( \mu f_1 - \frac{e_2}{\mu} \right)^2 - \frac{1}{4} \mu^2 f_1^2 - e_2 x_2 (\hat{\beta} - \beta + \rho) \tag{28}$$

It follows that the condition $F_1 < 0$ is satisfied only if

$$\hat{\beta} - \beta + \rho > 0 \tag{29}$$

Step 3: Real control law

The real control input to system in (11) is designed to ensure the dissipation condition in (13). Thus, a new function $F_2$ is constructed as follows

$$L_2 = \frac{d}{dt} \sum_{i=1}^{3} \left( \frac{1}{2} e_i^2 \right) + \frac{1}{2} \left( \|\boldsymbol{h}\|^2 - \mu^2 \sum_{i=1}^{2} (f_i^2) \right) \tag{30}$$

With $e_3 = x_3 - x_3^*$, one can obtain

$$\dot{e}_3 = -b_1(x_3 - T_0) + b_2 u$$
$$+ f_2 - \left[ \frac{a_2 \dot{x}_1 - (\hat{\beta} + \rho + \alpha_3) \dot{x}_2 - (\dot{\hat{\beta}} + \dot{\rho}) x_2}{a_2} \right] \tag{31}$$

It follows that

$$L_2 = -\alpha_1 e_1^{2.} - \frac{1}{2} \left( \mu f_1 - \frac{e_2}{\mu} \right)^2 - \frac{1}{4} \mu^2 f_1^2 - e_2 x_2 (\hat{\beta} - \beta + \rho)$$
$$e_3 \left( -b_1(x_3 - T_0) + b_2 u + f_2 - \left[ \frac{a_2 \dot{x}_1 - (\hat{\beta} + \rho + \alpha_3) \dot{x}_2 - (\dot{\hat{\beta}} + \dot{\rho}) x_2}{a_2} \right] \right) \tag{32}$$

The real control law for system in (11) is obtained as follows

$$u = \frac{1}{b_3} \left[ b_1(x_3 - T_0) + \frac{a_2 \dot{x}_1 - (\hat{\beta} + \rho + \alpha_3) \dot{x}_2 - (\dot{\hat{\beta}} + \dot{\rho}) x_2}{a_2} \right] \tag{33}$$

## C. Stability Analysis

To address the global stability of the SMA actuator, the dynamic model in (11) is put in an error form using the definitions (21), (23), and (30).

$$\begin{cases} \dot{e}_1 = e_2 + k_1 e_1 \\ \dot{e}_2 = -a_1 x_1 - \beta x_2 + a_2 x_3 + f_1 + k_1(e_2 - k_1 e_1) \\ \dot{e}_3 = (b_1 x_2(x_3 - T_0) + b_2 u + f_2 \\ \quad - \left[ \frac{a_2 \dot{x}_1 - (\hat{\beta} + \rho + \alpha_3) \dot{x}_2 - (\dot{\hat{\beta}} + \dot{\rho}) x_2}{a_2} \right] ) \end{cases} \tag{34}$$

Consider a Lyapunov candidate function $V = \sum_{i=1}^{3} \left( \frac{1}{2} e_i^2 \right)$, the function $L_2$ given in (30) can be written as follows.

$$L_2 = \dot{V} + \frac{1}{2} \left( \|\boldsymbol{h}\|^2 - \mu^2 \sum_{i=1}^{2} (f_i^2) \right) \tag{35}$$

From (33), it follows that $L_2 \le 0$ if and only if $\lim_{t \to \infty} (\hat{\beta} - \beta + \rho)$, thus.

$$\dot{V} \le -\frac{1}{2} \left( \|\boldsymbol{h}\|^2 - \mu^2 \sum_{i=1}^{2} (f_i^2) \right) \tag{36}$$

The integration of (36) for the case of $f_1 = f_2 = 0$ gives

$$V(t) \le V(0) - \frac{1}{2} \int_0^t \|\boldsymbol{h(t)}\|^2 \, dt \le V(0) \tag{37}$$

It can be seen from system in (35), that the origin ($e_1 = e_2 = e_3 = 0$) is globally stable. For the case of non-parametric uncertainties where $f_1 \neq 0, f_2 \neq 0$, the following semi-defined function is considered

$$W(\boldsymbol{e}, \boldsymbol{f}) = -\alpha_1 e_1^2 - \frac{1}{2}\left(\mu f_1 - \frac{e_2}{\mu}\right)^2 - \frac{1}{2}\left(\mu f_2 - \frac{e_3}{\mu}\right)^2$$

$$-\left(\frac{1}{2}\mu f_1 - \frac{(\alpha_2 + \hat{\beta} + \rho)e_3}{\mu a_3}\right)^2 - \left(e_2 - \frac{(\alpha_2 + \hat{\beta} + \rho)e_3}{\mu a_3}\right)^2 \varphi x_2 \tag{38}$$

From (35), it follows that

$$\dot{V} \leq -W(\boldsymbol{e}, \boldsymbol{f}) \leq 0 \tag{39}$$

According to Lasalle-Yoshizawa theorem [26], all solutions of (11) are globally uniformly asymptotically stable and satisfy the following condition $\lim_{t \to \infty} W = 0$.

### D. SMA-based Array Actuator

Consider the case of an array actuator where all the individual actuators are connected to the power supply source. The following distributed heat law is considered for thermal activation of the $i^{th}$ SMA actuator.

$$u_i = \frac{1}{b_3}\Big[b_1(x_{3,i} - T_0)$$

$$+ \frac{\alpha_2 \dot{x}_{1,i} - (\hat{\beta} + \rho + \alpha_3)\dot{x}_{2,i} - (\dot{\hat{\beta}} + \dot{\rho})\, x_{2,i}}{a_2}$$

$$k\left[\sum_{j \in \mathcal{N}} a_{ij}(\boldsymbol{x}_i - \boldsymbol{x}_j) + a_{i0}(\boldsymbol{x}_i - \boldsymbol{x}_d)\right] + \tag{40}$$

with $k \in \mathbb{R}^+$ is a control gain.

The control objective is achieved when all the actuators' states reach the desired value according to the following consensus

$$\left\{\lim_{t \to t_s}\|\boldsymbol{x}_i - \boldsymbol{x}_d\|_2 = 0\right. \tag{41}$$

where, $t_s$ is the settling time and $a_{ij}$ are the coefficients of the adjacency matrix of the activation topology.

### IV. NUMERICAL RESULTS

To demonstrate the efficacy of the theoretical developments, numerical calculations have been performed. Since the twist angle $\theta$ measures the actuating capability of the SMA rotary actuator, two desired twist angle paths are considered. First, the SMA wire is heated to its final austinite temperature $A_f$ to achieve the desired steady angle $\theta_t = 100°$. The SMA actuator was then heated between $A_s$ and $A_f$ to track a desired time-varying sinusoidal twist angle in the presence of external disturbances. The non-parametric uncertainties $f_1$ and $f_2$ are determined as follows:

$$\begin{cases} f_1 = ae^{b(T - T_0)}\sin(\xi) \\ f_2 = ae^{b(T - T_0)}\cos(\xi) \end{cases}$$

with $a = 1e - 7, b = 0.25$.

The thermomechanical properties of the selected $NiTi$ material and the actuator parameters used in this simulation are shown in Table I.

TABLE I. NiTi MATERIAL AND ACTUATOR PROPERTIES

| NiTi material | | Actuator wire | |
|---|---|---|---|
| property | Value | property | Value |
| $M_s, M_f$ (°C) | 18.4, 9 | $\rho$ ($kg/m^3$) | 6450 |
| $A_s, A_f$ (°C) | 34.5, 49 | $C_p$ ($J/Kg°C$) | 2046 |
| $C_m, C_a$ ($Pa/°C$) | 8e6, 13.8e6 | $d$ (mm) | 1.0 |
| $\sigma_{s_{cr}}, \sigma_{a_{cr}}$ (Pa) | 100e6,100e6 | $L_0$ (mm) | 100 |
| $\alpha_s, \alpha_f$ | 1.1e-6, 6.6e-6 | $R(\Omega)$ | 3.0 |
| $\epsilon_L$ | 0.067 | $T_0$ (°C) | 25 |

*Scenario 1*: A simulation of angle-temperature actuation was run to validate the single actuator control law (33). The twist angle achieved the desired $\theta_t = 100°C$ without overshooting, the temperature $T$ saturated around $70°C$ and the equivalent stress $\sigma$ reached $600\ MPa$. Fig. 2 shows the simulation results for with tuning of parameter $\mu$.

Fig. 3 demonstrates that when the suggested HARC method is applied, the transient response of the actuator states converges faster and without oscillation compared to other conventional adaptive backstepping control (CABC) methods.
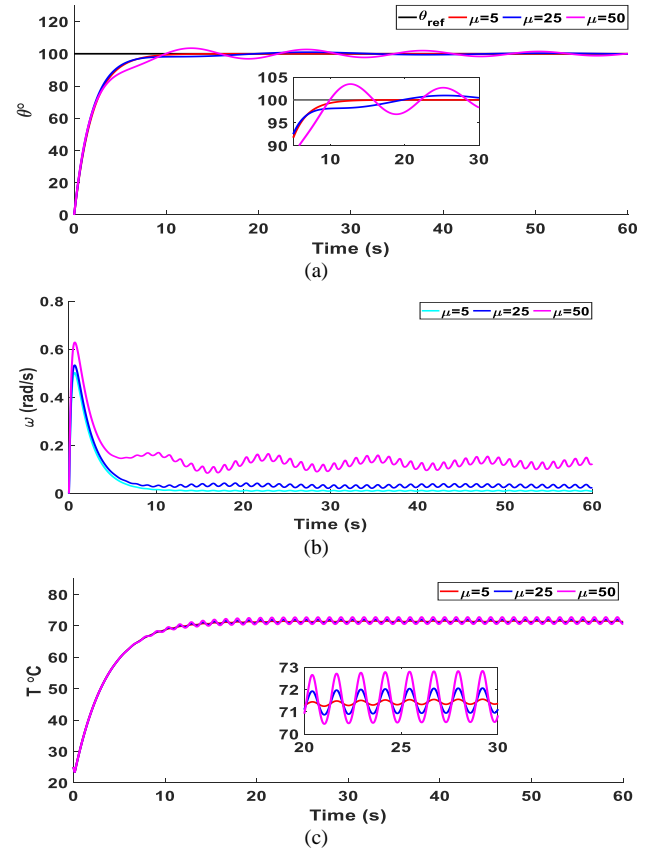


Fig. 2. Actuator transient response with tuning of parameter $\mu$: a) Twist angle $\theta$, b) rotary velocity $\omega$, and c) heating temperature $T$.

Fig. 4.   Actuation topology for a four-SMA actuator.



Fig. 3.   Comparison between proposed HARC and CABC methods: (a) Twist angle $\theta$, (b) rotary velocity $\omega$, and (c) heating temperature $T$, d) parametric estimator $\beta$.

*Scenario 2:* To simulate the cooperative actuation of an array SMA actuator to overcome individual actuator load bearing limitation, a cooperative task is attributed to a set of four actuators to track a sinusoidal twist angle $\theta_t(t) = 60sin(0.5t)(°)$. The actuators were put under initial conditions of temperature $T = [\ 25\ 50\ 65\ 80]^{°}C$ and initial twist angle $\theta = [-20\ -60\ 60\ 120]^{°}$. A disturbance of $\Delta T = 5°C$ is introduced at $t = 20\ s$ simulating a sudden change in the electrical current and checking the controller's robustness.

The four actuators were actuated according to activation topology shown in Fig. 4. The distributed control law in (41) is used to activate the array controller and the results are shown in Fig. 5.

Fig. 5. Simulation results for a multi-SMA actuator under time-varying actuation topology: a) twist angle, b) angular speed, c) temperature, and d) stress-strain diagram.

*Remark 1:* Fig. 3 shows a fair comparison between the proposed hybrid adaptive robust control scheme and one of the conventional backstepping control approaches. The comparison shows that the hybrid approach provide high-performance and more stable transient response rather than the conventional solution that ignores the nonlinear effect of the system parameters.

*Remark 1*: Fig. 3(d) shows that the parameter estimator $\hat{\theta}(t)$ starting from the initial condition $\hat{\theta}(0) = 0$ converges to its steady-state value $\theta_{ss} = 2$ without oscillation.

*Remark 2*: Changing the design parameter $\mu$ in (24), the transient response of the twist angle, angular speed, and temperature states are affected as shown in Figure 4. The tuning of the parameter $\mu$ directly affects the convergence of the actuator states. Short settling time, small fluctuations, and stable response are obtained with small values of $\mu$.

## V. CONCLUSION

This paper proposed a hybrid adaptive robust control approach for thermal activation of a multi-SMA rotary actuator in the presence of parametric and non-parametric uncertainties using adaptive backstepping control. First, a control method that integrates adaptive immersion and invariance (I&I adaptive) control, $L_2$-gain control, a parameter estimation law, and asymptotic smooth disturbance functions for induced effect of SMA phase transformation was developed. Pre-defined target system and PDEs solving process, presented in the conventional adaptive backstepping methods, were skipped altogether. Then, the developed control scheme was extended to actuate a multi-agent or array controller where a cluster of controllers are used together to cooperate for load bearing beyond their individual capabilities. The distributed control protocols were designed to work in coordination under switching activation topology to avoid excessive current supply and minimize the activation cost. Different simulation scenarios for tracking the target twist angle, thermal load disturbance, and parameter tuning have been carried out to demonstrate the effectiveness of the suggested control method. From what can be seen in simulation results, the suggested hybrid adaptive robust control method offers a viable solution for improving the performance of SMA actuators mainly in terms of stability and robustness. Future works will consider the trade-off between actuator performance and parameter tuning and will extend the proposed control method to other types of SMA controllers.

### REFERENCES

[1] S. K. Yadav, Shape Memory Alloy Actuators: A Review, Int. J. Res. Appl. Sci. Eng. Technol., 7 (5) (2019) 799–802. doi: 10.22214/ijraset.2019.5134.

[2] T. Devashena and K. Dhanalakshmi, Simultaneous Measurements in Shape Memory Alloy Springs to Enable Structural Health Monitoring by Self-Sensing Actuation, Arabian Journal for Science and Engineering, 46 (2021) 6015-6025.

[3] D. K. Soother, J. Daudpoto, and B. S. Chowdhry, Challenges for practical applications of shape memory alloy actuators, Mater. Res. Express, vol. 7 (7) (2020). doi: 10.1088/2053-1591/aba403.

[4] H. Yuan, J. C. Fauroux, F. Chapelle, and X. Balandraud, A review of rotary actuators based on shape memory alloys, J. Intell. Mater. Syst. Struct., 28 (14) (2017) 1863–1885. doi: 10.1177/1045389X16682848.

[5] M. Sansone, S. Ameduri, A. Concilio, and E. Cestino, Understanding Shape Memory Alloy Torsional Actuators: From the Conceptual to the Preliminary Design," Actuators, vol. 11, no. 3, pp. 1–25, 2022. doi: 10.3390/act11030081.

[6] N. Simiriotis, M. Fragiadakis, J. F. Rouchon, and M. Braza, Shape control and design of aeronautical configurations using shape memory alloy actuators, Comput. Struct., 244 (2021). doi: 10.1016/j.compstruc.2020.106434.

[7] K. Hu, K. Rabenorosoa, and M. Ouisse, A Review of SMA-Based Actuators for Bidirectional Rotational Motion: Application to Origami Robots, Front. Robot. AI, 8 (2021) 1–21. doi: 10.3389/frobt.2021.678486.

[8] D. J. S. Ruth, J. W. Sohn, K. Dhanalakshmi, and S. B. Choi, Control Aspects of Shape Memory Alloys in Robotics Applications: A Review over the Last Decade, Sensors, 22 (13) (2022) 1–17. doi: 10.3390/s22134860.

[9] A. El Naggar and M. A. Youssef, Shape memory alloy heat activation: State of the art review, AIMS Mater. Sci., 7 (6) (2020) 836–858, 2020. doi: 10.3934/matersci.2020.6.836.

[10] J. S. Owusu-DanquahA. F. Saleeb, On the modeling of the effect of processing and heat treatment on actuation behaviors of high temperature ternary and quaternary shape memory alloys, J. Alloys Compd., 714 (2015) 493–501.

[11] J. Guo, C. Zhao, and Z. Song, Discussion on research status and key technologies of morphing aircraft, J. Phys. Conf. Ser., 2228 (1) 2022. doi: 10.1088/1742-6596/2228/1/012021.

[12] S. Karmakar, V. Gaddam, J. Kim, A. K. Mishra, and A. Sarkar, Helical SMA Actuator based Artificial Muscle and Arm with Sliding Mode Control, ACM Int. Conf. Proceeding Ser., (2021) 1–5. doi: 10.1145/3478586.3480722.

[13] N. Keshtkar, S. Keshtkar, and A. Poznyak, Deflection sliding mode control of a flexible bar using a shape memory alloy actuator with an uncertainty model, Appl. Sci., 10 (2) (2020). doi: 10.3390/app10020471.

[14] F. O. M. Joseph and T. Podder, "Sliding mode control of a shape memory alloy actuated active flexible needle," Robotica, 36, (8) (2018) 1188–1205. doi: 10.1017/S0263574718000334.

[15] R. Hmede, F. Chapelle, and Y. Lapusta, Review of Neural Network Modeling of Shape Memory Alloys, Sensors, 22 (15) (2022). doi: 10.3390/s22155610.

[16] A. Mendizabal, P. Márquez-Neila, and S. Cotin, Simulation of hyperelastic materials in real-time using deep learning, Med. Image

Anal., 59 (2020) 1–11. doi: 10.1016/j.media.2019.101569.

[17] J. S. Owusu-Danquah, A. Bseiso, and S. Allena, Artificial neural network models to predict the response of 55NiTi shape memory alloy under stress and thermal cycles, Neural Computing and Applications, 34 (5) (2022). 3829–3842. doi: 10.1007/s00521-021-06643-x.

[18] A. Gómez-Espinos, R. C. Sundin, I. L. Eguren, E. Cuan-Urquiz, and C. D. Treviño-Quintanilla, Neural network direct control with online learning for shape memory alloy manipulators, Sensors, 19(11) (2019) 1–17. doi: 10.3390/s19112576.

[19] R. E. Precup, C. A. Bojan-Dragos, E. L. Hedrea, R. C. Roman, and E. M. Petriu, Evolving Fuzzy Models of Shape Memory Alloy Wire Actuators, Rom. J. Inf. Sci. Technol., 24 (4) (2021) 353–365.

[20] K. Suwat, Adaptive Fuzzy Sliding-Mode Position Control of a Shape Memory Alloy Actuated System. Applied Mechanics and Materials, vol. 789–790, Trans Tech Publications, Ltd., (2015) 946–950.

[21] L. Su and X. Zhao, Prescribed Adaptive Backstepping Control of Nonlinear Systems Preceded by Hysteresis in Piezoelectric Actuators, Int. J. Precis. Eng. Manuf. 23 (2022) 733-740.

[22] A. M. Khan, B. Shin, M. Usman, and Y. Kim, Backstepping control of novel arc-shaped SMA actuator, Microsyst. Technol., 28 (10) (2022) 2191–2202. doi: 10.1007/s00542-022-05250-7.

[23] J. M. Jani, S. Huang, M. Leary, and A. Subic, Numerical modeling of shape memory alloy linear actuator, Comput. Mech., 56 (3) (2015) 443–461. doi: 10.1007/s00466-015-1180-z.

[24] W. Wang, Y Xiang, J Yu, L Yang, Development and Prospect of Smart Materials and Structures for Aerospace Sensing Systems and Applications. Sensors (Basel). 23(3) (2023) 1545. doi: 10.3390/s23031545.

[25] M. H. Elahinia and M. Ahmadian, An enhanced SMA phenomenological model: I. The shortcomings of the existing models, Smart Mater. Struct., 14 ( 6) (2005) 1297–1308. doi: 10.1088/0964-1726/14/6/022.

[26] C. Liang and C. A. Rogers, One-Dimensional Thermomechanical Constitutive Relations for Shape Memory Materials, J. Intell. Mater. Syst. Struct., 1 (2) (1990) 207–234. doi: 10.1177/1045389X9000100205.

[27] D. Karagiannis and A. Astolfi, Nonlinear adaptive control of systems in feedback form: An alternative to adaptive backstepping, Syst. Control Lett., 57 (9) (2008) 733–739, 2008. doi: 10.1016/j.sysconle.2008.02.006.

# Dimensionality Reduction with Truncated Singular Value Decomposition and K-Nearest Neighbors Regression for Indoor Localization

Hang Duong Thi[1], Kha Hoang Manh[2*], Vu Trinh Anh[3], Trang Pham Thi Quynh[4], Tuyen Nguyen Viet[5]

Faculty of Electronics and Engineering, Hanoi University of Industry[1, 2, 4, 5]

Department of Electronics and Telecommunication, University of Engineering and Technology, Vietnam National University[1, 3]

*Abstract*—**Indoor localization presents formidable challenges across diverse sectors, encompassing indoor navigation and asset tracking. In this study, we introduce an inventive indoor localization methodology that combines Truncated Singular Value Decomposition (Truncated SVD) for dimensionality reduction with the K-Nearest Neighbors Regressor (KNN Regression) for precise position prediction. The central objective of this proposed technique is to mitigate the complexity of high-dimensional input data while preserving critical information essential for achieving accurate localization outcomes. To validate the effectiveness of our approach, we conducted an extensive empirical evaluation employing a publicly accessible dataset. This dataset covers a wide spectrum of indoor environments, facilitating a comprehensive assessment. The performance evaluation metrics adopted encompass the Root Mean Squared Error (RMSE) and the Euclidean distance error (EDE)—widely embraced in the field of localization. Importantly, the simulated results demonstrated promising performance, yielding an RMSE of 1.96 meters and an average EDE of 2.23 meters. These results surpass the achievements of prevailing state-of-the-art techniques, which typically attain localization accuracies ranging from 2.5 meters to 2.7 meters using the same dataset. The enhanced accuracy in localization can be attributed to the synergy between Truncated SVD's dimensionality reduction and the proficiency of KNN Regression in capturing intricate spatial relationships among data points. Our proposed approach highlights its potential to deliver heightened precision in indoor localization outcomes, with immediate relevance to real-time scenarios. Future research endeavors involving comprehensive comparative analyses with advanced techniques hold promise in propelling the field of accurate indoor localization solutions forward.**

*Keywords—Dimensionality Reduction; Indoor Positioning System; KNN regression; Truncated Singular Value Decomposition*

## I. INTRODUCTION

Indoor positioning has become a prominent research area in recent years, driven by the increasing demand for location-based services in various applications, such as indoor navigation, asset tracking, and context-aware services. Traditional positioning systems relying on Global Positioning System (GPS) are not always reliable indoors due to limited satellite signals penetration and multi-path effects, making them less accurate for indoor environments. This limitation has led to the emergence of alternative techniques, with machine learning proving to be a promising approach for indoor positioning tasks. Machine learning methods offer the ability to model complex relationships between Wi-Fi Received Signal Strength Indicator (RSSI) measurements and indoor locations, enabling accurate predictions in indoor settings [1]. Among the diverse machine learning algorithms, the K-Nearest Neighbors (KNN) algorithm has garnered significant attention and success in indoor positioning applications [2, 3]. KNN is a non-parametric and instance-based learning algorithm that classifies or predicts a target value based on the similarity of features from neighboring data points. Its simplicity and effectiveness have made it a popular choice for indoor positioning tasks. However, the conventional KNN algorithm can be sensitive to noise and imbalanced data, necessitating the exploration of specialized variants to improve performance.

One such variant is the Weighted K-nearest neighbors (WKNN), which assigns different weights to neighboring data points based on their distance or other factors [4]. This enables WKNN to give higher importance to closer points, leading to more accurate predictions and better handling of imbalanced data distributions. The authors in study [4] propose a method that utilizes Improved W-KNN to enhance indoor localization performance based on fingerprinting by leveraging the relationship between the nearest fingerprint and (K-1) auxiliary fingerprints to determine the position. In the quest for enhanced adaptability, Adaptive KNN adjusts the number of neighbors (K) based on the local density of data points, dynamically tailoring the algorithm to varying spatial distributions within the indoor environment [5]. The paper introduces an enhanced KNN algorithm featuring a variable K. The fundamental concept revolves around dynamically modifying the K value according to the discrepancies between measured signals and the corresponding values within the database. In this paper, adaptability contributes to improved performance across different regions with distinct data densities. Additionally, KNN Regression is used when predicting continuous target variables, such as indoor coordinates, making it particularly suitable for regression tasks in indoor positioning. Apart from KNN-based methods, deep learning techniques have also been explored for indoor positioning. Convolutional Neural Networks (CNN) [6, 7] and Long Short-Term Memory (LSTM) [8] networks are notable examples. CNN can effectively extract spatial features from Wi-Fi images, while LSTM can model temporal dependencies in time-series data, such as RSSI signals. In [7], the authors introduces an innovative method for converting Wi-Fi signatures into

images, establishing a scalable fingerprinting framework utilizing convolutional neural networks (CNNs), These deep learning models have shown promise in achieving high accuracy in indoor positioning tasks, but they may require more extensive datasets and computation resources.

The authors in [9, 10] conducted an overview study on several data dimensionality reduction methods and their effectiveness in reducing computation time while preserving information. Data preprocessing is of paramount importance in indoor positioning tasks to enhance model performance and reduce computational complexity. High-dimensional Wi-Fi RSSI data can be computationally intensive and challenging to handle. To address this issue, dimensionality reduction techniques are applied to retain critical information while significantly reducing the number of features. Principal Component Analysis (PCA) is a popular method for dimensionality reduction, but it may not be ideal for all scenarios due to its requirement for the data to be centered and scaled. As an alternative, Truncated Singular Value Decomposition (Truncated SVD) [11] is employed, which is a variant of PCA that can efficiently handle large datasets and does not require data centering. In this paper, we propose an approach for indoor positioning that combines Truncated SVD for dimensionality reduction of Wi-Fi RSSI data with KNN regression for accurate indoor location estimation. The solutions mentioned above all aim to reduce errors in location estimation. However, a challenge arises in studies using Wi-Fi signals, where the use of high-dimensional data complicates the training process due to the time required for both training and prediction. Therefore, reducing data dimensionality is considered an effective solution to reduce model complexity and simultaneously enhance data processing flexibility. Combining Truncated SVD and KNN Regression yields a flexible method applicable to various indoor positioning scenarios, not constrained by specific data structures or characteristics. The proposed approach will be extensively evaluated and compared with other state-of-the-art methods to demonstrate its effectiveness and applicability.

In the subsequent sections, we will delve into the details which are as follows: Section II is about the related works, Section III deals with the proposed approach. Section IV gives results, and discussion, and concludes with implications for future research in Section V, thereby contributing to the advancement of indoor positioning technology and its real-time applications.

## II. RELATED WORKS

### A. Challenges in Indoor Localization using Wi-Fi Signals

Addressing the problem of enhancing accuracy in indoor positioning still encounters numerous difficulties due to the persistence of challenges such as limited GPS signals. Unlike outdoor environments where Global Positioning System (GPS) signals are readily available, indoor spaces often lack direct access to GPS signals due to signal attenuation caused by walls, ceilings, and other structural elements. This limitation hampers the effectiveness of traditional GPS-based localization techniques. Multipath effects further complicate indoor positioning. Indoor environments introduce multipath effects, where wireless signals bounce off surfaces and create multiple

signal paths. This leads to signal interference, phase shifts, and fluctuations, making signal strength-based localization less accurate and reliable. Moreover, signal propagation variability within indoor spaces can vary significantly due to factors such as furniture placement, architectural elements, and interference from electronic devices. This variability challenges the establishment of consistent and reliable signal patterns for accurate localization. Non-line-of-sight (NLOS) conditions due to obstructions like walls and obstacles can block the direct line between the transmitter and receiver, introducing additional complexities in signal propagation and affecting accuracy. The phenomenon of multipath fading, where signals arriving via different paths interfere constructively or destructively, contributes to signal fluctuations and inaccuracies in distance estimation. Dealing with high-dimensional data, such as Wi-Fi Received Signal Strength Indicator (RSSI) readings from multiple access points, is a computational challenge in indoor localization. The presence of interference and noise from electronic devices further impacts the accuracy of localization algorithms. Different indoor environments with unique layouts and architectural features add complexity to localization algorithms, as a one-size-fits-all approach may not be effective. Privacy concerns arising from collecting and analyzing personal data in indoor localization require careful consideration of data handling and user consent. Furthermore, many indoor localization applications demand real-time accuracy for guiding users or tracking assets, posing a challenge in achieving both precision and speed. Addressing these challenges necessitates innovative techniques that consider the intricacies of indoor environments. The proposed methodology aims to tackle these obstacles by combining dimensionality reduction and regression techniques for accurate indoor localization. In the context of employing methods such as K-Nearest Neighbors (KNN), Weighted K-Nearest Neighbors (WKNN), Adaptive K-Nearest Neighbors (Adaptive KNN), Convolutional Neural Networks (CNN), and Long Short-Term Memory (LSTM) for indoor position prediction, various limitations become apparent. For K-Nearest Neighbors (KNN), its sensitivity to the choice of K neighbors introduces computational complexities as K increases. Additionally, KNN is sensitive to noise and imbalanced data. Weighted K-Nearest Neighbors (WKNN) presents challenges in effectively setting weight parameters to enhance prediction performance. Adaptive K-Nearest Neighbors (Adaptive KNN) involves uncertainty in dynamically determining the optimal number of neighbors (K) for individual cases. Convolutional Neural Networks (CNN) demand substantial training data and computational resources, especially in real-time scenarios. Long Short-Term Memory (LSTM) requires longer time-series data for complex pattern recognition. Overall, while these methods offer unique strengths to tackle indoor positioning challenges, they also exhibit limitations, necessitating careful customization and consideration of the specific environment for an effective solution.

To address these challenges comprehensively, innovative techniques that account for the intricacies of indoor environments are indispensable. The proposed methodology aims to overcome these hurdles by synergistically employing dimensionality reduction techniques and regression methodologies for accurate indoor localization. The ensuing

sections delve into the details of this approach, experimental evaluation, and results, underscoring its efficacy in tackling these persistent challenges and enhancing indoor positioning accuracy.

### B. Dimensionality Reduction Techniques

In the realm of indoor positioning, addressing the challenges posed by high-dimensional data is crucial for achieving accurate and efficient results. This section provides an overview of various dimensionality reduction techniques that have been employed to tackle the complexity of indoor positioning datasets. Dimensionality reduction aims to extract essential information from the data while reducing its dimensionality, thus enhancing the efficiency of subsequent analysis and prediction processes.

One commonly used technique is Principal Component Analysis (PCA) [12-14], which projects the original data onto a new orthogonal coordinate system defined by its principal components. By retaining the most significant dimensions and discarding less informative ones, PCA simplifies the data representation while preserving as much variance as possible. Another approach, [15] Truncated SVD, is a variant of PCA that efficiently approximates the original data matrix by retaining only the top singular values and corresponding singular vectors. This method is particularly suitable for large datasets and offers advantages in terms of computational efficiency.

In addition to these techniques, various other methods can also play a role in dimensionality reduction. However, the choice of method depends on the characteristics of the data and the specific requirements of the indoor positioning task. By effectively reducing the dimensionality of the input data, these techniques contribute to enhancing the performance of subsequent algorithms and models for accurate indoor positioning. The following sections will delve into the details of how these techniques are applied and their impact on the proposed methodology.

*1) Truncated* singular value decomposition (Truncated SDV) Method: The Truncated Singular Value Decomposition (Truncated SVD) method is a dimensionality reduction technique commonly employed to mitigate the challenges associated with high-dimensional data in various applications, including indoor positioning. This approach builds upon the concept of Singular Value Decomposition (SVD), which decomposes a data matrix into three separate matrices representing its singular values and corresponding left and right singular vectors. In the context of indoor positioning, Truncated SVD involves retaining only the top singular values and their corresponding singular vectors, effectively reducing the dimensionality of the data while preserving its essential information. This process is particularly beneficial for managing large datasets, as it significantly decreases the computational burden and enhances the efficiency of subsequent analysis. The core idea of Truncated SVD is to approximate the original data matrix using a lower-dimensional representation that captures the most significant patterns and relationships within the data. By selecting a

specific number of singular values to retain, this method allows researchers and practitioners to balance between dimensionality reduction and preserving relevant information.

Truncated SVD finds applications in various fields, including image processing, natural language processing, and data compression. In the context of indoor positioning, it offers a valuable tool for preprocessing Wi-Fi Received Signal Strength Indicator (RSSI) data, effectively reducing its dimensionality while maintaining its inherent structure. The reduced-dimension representation obtained through Truncated SVD can then be used as input for subsequent algorithms, such as K-Nearest Neighbors (KNN) regression, to enhance the accuracy and efficiency of indoor positioning predictions. The goal of Truncated SVD is to reduce the dimensionality of the data by retaining a limited number of important singular values and vectors. This helps to simplify the complexity of the original data and create a reduced version that can be used in various tasks such as classification, prediction, and indoor positioning. Algorithm 1 presents Truncated SVD Algorithm.

---

**Algorithm 1: Truncated SVD Algorithm**

**Input:** The initial data is a matrix A with dimensions m x n, where m is the number of samples and n is the dimensionality of the data.

**Output:** The matrix A_reduced represents the reduced data and includes the most important components from the original data.

**Step 1: Compute Singular Value Decomposition (SVD):** Perform the Singular Value Decomposition on the data matrix **A**: $A = U * \Sigma * Vt$
Where:

- **U** is the matrix containing the left singular vectors (columns) of A.
- **Σ** is the diagonal matrix containing the singular values of A.
- **Vt** is the matrix containing the right singular vectors (rows) of A.

**Step 2: Select Number of Components:** Choose the number of components (singular values and vectors) that you want to retain after dimensionality reduction. This is an important parameter to adjust the level of dimensionality reduction.

**Step 3: Truncate Singular Values and Vectors:** Keep only the singular values and vectors corresponding to the number of components selected in the previous step. Create the truncated matrices **U** reduced and **Vt** reduced.

**Step 4: Reconstruct Reduced Data:** Generate a new data matrix (reduced data) by multiplying the truncated matrix **U** reduced, the diagonal matrix **Σ** reduced (containing singular values), and the transpose of the matrix Vt_reduced: $A\_reduced = U\_reduced * \Sigma\_reduced * Vt\_reduced$

---

*2) K nearest neighbors regression algorithm:* KNN regression is a non-parametric algorithm that relies on the similarity of feature vectors to make predictions. It assumes that similar instances will have similar target values. The algorithm doesn't involve model training like some other regression algorithms; instead, it stores the entire dataset and calculates predictions based on the K nearest neighbors of the

query instance. The choice of K is crucial, as a small K might lead to noisy predictions, while a large K might lead to overly smoothed predictions. KNN regression can be sensitive to outliers and irrelevant features, so preprocessing the data and feature selection can impact its performance. Fig. 1 describes the KNN regression for improving the accuracy of indoor localization.
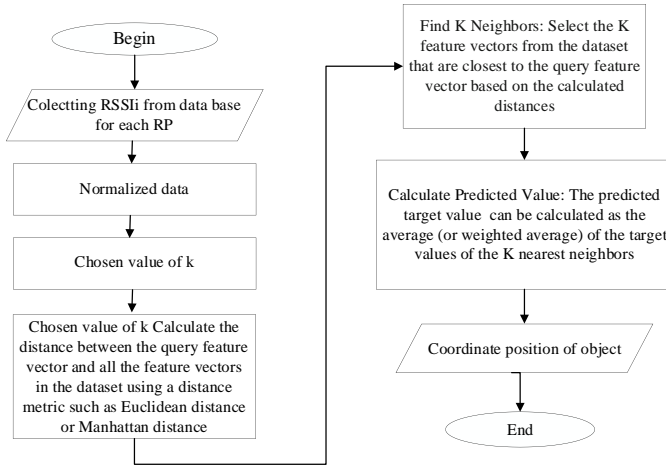


Fig. 1. The algorithm of WKNN for indoor positioning system.

### III. PROPOSED APPROACH

This section presents the proposed solution that combines dimensionality reduction using Truncated Singular Value Decomposition (Truncated SVD) with KNN regression for indoor position prediction.

### A. Proposal Model Block Diagram

Fig. 2 describes the block diagram illustrates the proposed approach that integrates two main components: Truncated Singular Value Decomposition (Truncated SVD) and K Nearest Neighbors (KNN) regression. The process begins with the collection of Wi-Fi RSSI data, which is the initial step for indoor position prediction.
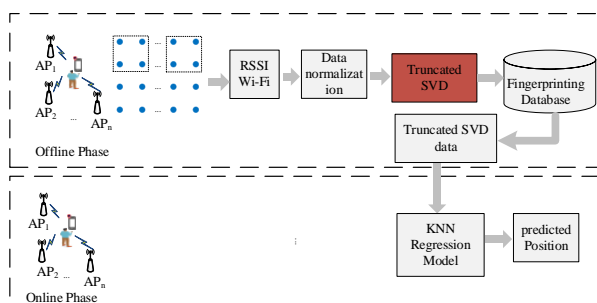


Fig. 2. The structure of proposed approach based on KNN regression.

**Data collection and preprocessing:**

- Wi-Fi RSSI data is gathered from multiple access points within the indoor environment.

- The collected data is preprocessed to remove noise, handle missing values, and normalize the features.

**Truncated Singular Value Decomposition (Truncated SVD):**

- The preprocessed Wi-Fi RSSI data undergoes Truncated SVD, a dimensionality reduction technique.

- Truncated SVD reduces the dimensionality of the data while retaining the most significant features that capture the underlying patterns.

- The transformed data is then ready for further processing.

**K Nearest Neighbors (KNN) regression:**

- The transformed data from Truncated SVD serves as input to the KNN regression model.

- KNN regression aims to predict the indoor position based on the similarity of the transformed data points.

- The model identifies the K nearest neighbors to the input data point and uses their positions to estimate the target position.

**Indoor position prediction:**

- The combination of Truncated SVD and KNN regression results in an accurate indoor position prediction.

- The estimated position is output as the final result of the model.

The block diagram demonstrates how the proposed method utilizes Truncated SVD for dimensionality reduction to handle the high-dimensional Wi-Fi RSSI data effectively. The reduced-dimensional data is then fed into the KNN regression model, which leverages the spatial relationships between data points to predict the indoor position accurately. This integrated approach aims to overcome the challenges of noise, signal variability, and dimensionality while providing enhanced precision in indoor position prediction.

### B. Indoor Positioning Dataset

In this study, we assessed our proposed solution using an online dataset [16], previously standardized for indoor positioning research. This dataset, employed in previous work including [17] aimed to enhance indoor positioning precision by LSTM algorithms. The study in [6] achieved a positioning error are range 2.5 meters to 2.7 meters on the public dataset [16]. The paper [16] verified the dataset's normalization and reliability for indoor localization research. The dataset covered a library space of over 300 square meters on the 3rd and 5th floors, collected over 15 months, and comprising 60,000 measurements. It included object positions, Wi-Fi AP access point RSSI values, execution time, and identification data. With 448 Wi-Fi AP access points at around 2.65 meters above the ground on both floors, a fingerprint database was created from multiple locations and directions, including front, back, left, and right measurements. Offline training involved known reference points and a Samsung Galaxy S3 phone equipped with an application to capture RSSI data. The dataset was divided into training (16,704 fingerprints from 24 reference points) and test sets (46,800 fingerprints from 106 reference points), each containing 448 RSSI indicators from access points. Following the approach of [6], our experiments on the

normalized public dataset utilized the Minmaxscale() function and Formula (1).

$$X_{scaled} = \frac{X - X_{min}}{X_{max} - X_{min}} \qquad (1)$$

where $X$ is the initial value of the feature, $X_{max}$ and $X_{min}$ are the maximum and minimum values in the feature.

## C. Error Estimation Criteria

We employed four machine learning-based evaluation criteria to assess the proposed solution's effectiveness. Initially, we used the mean absolute error (MAE) to gauge the average absolute error within the prediction dataset. Further evaluation employed mean squared error (MSE) or RMSE, widely utilized in machine learning regression problems, to quantify the squared error between predicted and actual values. Additionally, the determination coefficient R2 was employed as a measure of the model's predictive capability. R2 assesses how well the model predicts the dependent variable based on independent variables, showcasing the goodness-of-fit. Higher R2 values signify better model fit, with a range from 0 to 1. Negative values can emerge if the model performs worse than a constant model predicting the mean. Despite its usefulness, R2 has assumptions and limitations that warrant consideration. This coefficient's range lies between 0 and 1. A value closer to 1 indicates strong model fit and accurate prediction of position.

Furthermore, we introduced the EDE as an additional metric to measure prediction accuracy. The EDE calculates the direct geometric distance between predicted and actual positions, offering a straightforward measure of how far the predictions deviate from the true positions. This distance was calculated using the Euclidean distance formula, providing valuable insight into the spatial accuracy of the proposed solution.

$$MAE = \frac{1}{N_{test}} \sum_{i=1}^{N_{test}} \left| Pos_{itrue} - Pos_{iest} \right| \qquad (2)$$

$$MSE = \frac{1}{N_{test}} \sum_{i=1}^{N_{test}} \left( Pos_{itrue} - Pos_{iest} \right)^2 \qquad (3)$$

$$RMSE = \sqrt{\frac{1}{N_{test}} \sum_{i=1}^{N_{test}} \left( Pos_{itrue} - Pos_{iest} \right)^2} \qquad (4)$$

$$R^2 = 1 - \frac{\sum_{i=1}^{N_{test}} \left( Pos_{itrue} - Pos_{iest} \right)^2}{\sum_{i=1}^{N_{test}} \left( Pos_{itrue} - avg(y) \right)^2} \qquad (5)$$

$$avg(y) = \frac{1}{N_{test}} \sum_{i=1}^{N_{test}} Pos_{itrue}$$

$$EDE = \frac{1}{N_{test}} \sum_{1}^{n} \sqrt{\left( Pos_{itrue} - Pos_{iest} \right)^2} \qquad (6)$$

Where $Pos_{itrue}$ is the $i-th$ observed position, $Pos_{itest}$ is the $i-th$ estimation position. $i-th$ is the number of samples in the test dataset.

## IV. RESULTS AND DISCUSSION

In this study, we conducted a thorough investigation to determine the optimal number of principal components (components) to retain when applying the truncated SVD technique. The objective was to minimize the EDE, a critical metric for assessing the accuracy of our proposed indoor positioning solution.

The process of choosing the appropriate value for components began with a systematic survey across a range of values, assessing the performance of the solution at each step. We employed the EDE as the primary evaluation criterion, aiming to identify the component's value that yielded the lowest error. Our experimentation revealed that at the number of components = 35, the solution achieved the minimal EDE. This observation was consistent with our goal of minimizing error while ensuring computational efficiency, as retaining 35 principal components struck an optimal balance between accuracy and resource consumption. By retaining 35 principal components, we effectively reduced the dimensionality of the data while preserving the critical information necessary for accurate indoor localization. This choice optimized the model's ability to capture relevant spatial relationships among data points, resulting in a significant reduction in the EDE. In conclusion, our survey and experimentation led us to select the number of components = 35 as the optimal configuration for the truncated SVD algorithm. This choice aligns with our objective of achieving the lowest EDE while maintaining efficiency, demonstrating the effectiveness of this approach in improving indoor positioning accuracy.

The analysis of Fig. 3, which depicts the relationship between the number of components in truncated SVD (n) and the EDE, reveals several key insights:

Firstly, at n = 35, we observe the lowest EDE, indicating that this configuration results in the most accurate indoor positioning predictions. This point aligns with our earlier discussion, highlighting n = 35 as the optimal choice for retaining principal components. When n is smaller than 35, the reduction in dimensionality becomes excessive, leading to a loss of critical information required for accurate localization.



Fig. 3. The relationship between the number of truncated SVD components and euclidean distance error.

Conversely, when the numbers of components (n) are greater than 35, the model becomes overly complex, potentially introducing noise and diminishing its predictive capabilities. The fact that the EDE consistently rises for values of n smaller or larger than 35 emphasizes the importance of careful parameter tuning in the truncated SVD technique. It highlights the delicate balance between dimensionality reduction and information preservation.
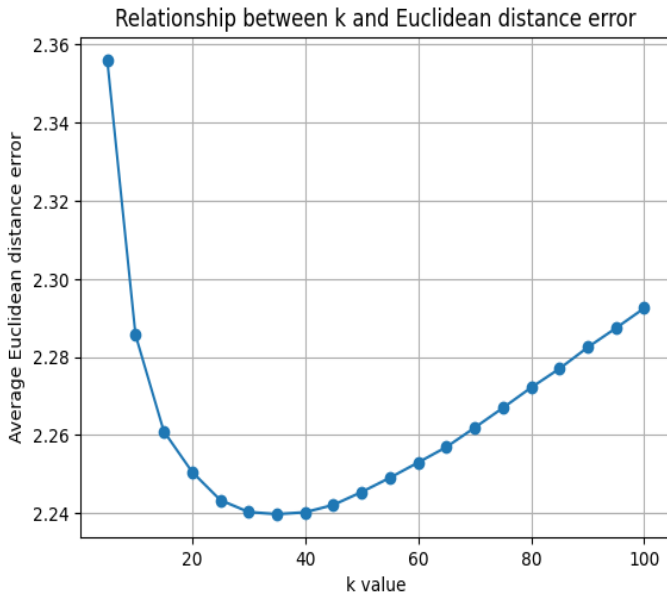


Fig. 4.   The relationship between k and euclidean distance error.

Fig. 4, which illustrates the relationship between the number of nearest neighbors (k) and the EDE, provides crucial insights into our study. The plot demonstrates a clear trend that supports the idea that selecting k = 30 is an optimal choice for our KNN regression-based indoor positioning solution. This specific k-value results in the lowest EDE, indicating the highest precision in predicting indoor positions. When k deviate from this optimal k-value, either by choosing k values smaller or larger than 30, we consistently observe an increase in EDE. This pattern emphasizes the sensitivity of our model's performance to the choice of k. If k is smaller than 30, the model may not adequately capture essential spatial relationships, leading to less accurate predictions. Conversely, when k exceeds 35, the model might over smooth the data, potentially losing critical local information, which results in increased prediction errors. The observation that EDE increases for k values smaller or larger than 30 underscores the importance of selecting the appropriate parameter for KNN regression. It reinforces the idea that finding the right balance in the number of neighbors considered is vital for achieving accurate indoor localization. Fig. 4 highlights the significance of choosing k = 30 as the optimal parameter for our KNN regression-based indoor positioning solution. This choice leads to the lowest EDE value, indicating the highest accuracy in position prediction. Deviating from this value consistently results in increased EDE, affirming the effectiveness of our proposed approach in enhancing indoor localization accuracy.

Fig. 5 provides a visual representation of 100 randomly selected real positions (depicted as blue dots) and their corresponding predicted positions (depicted as red dots). This graph serves as a valuable illustration of the performance of our indoor positioning model. The meanings of the parameters on Fig. 5 are described below:
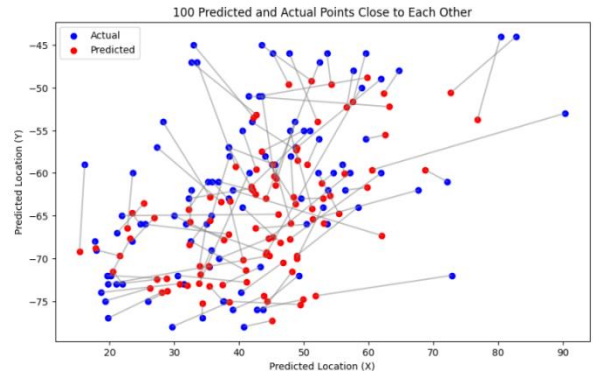


Fig. 5.   100 predicted and real positions.

*1) Blue dots - real positions:* The blue dots represent the actual positions of objects in the indoor environment, providing a reference for the ground truth. These positions are based on the collected dataset.

*2) Red dots - predicted positions:* The red dots, on the other hand, signify the positions predicted by our proposed indoor positioning model. These predictions are generated using the combination of Truncated SVD for dimensionality reduction and KNN regression for position estimation.

*3) Visual comparison:* By visually comparing the red and blue dots, it's evident that our model's predictions are generally very close to the actual positions. This alignment between the predicted and actual positions highlights the accuracy and effectiveness of our proposed solution.

*4) Scattered distribution:* The distribution of both red and blue dots across the graph demonstrates that the model is capable of predicting positions in various locations throughout the indoor environment. This showcases the versatility and applicability of our approach across different scenarios.

*5) Few outliers:* While most of the red dots closely match the blue dots, there may be a few outliers where the predicted positions slightly deviate from the actual positions. These outliers could be attributed to factors such as signal interference or complex spatial relationships in the indoor environment.

Fig. 5 visually reinforces the accuracy and reliability of our proposed indoor positioning solution. The close alignment between the predicted and actual positions across a range of locations underscores the model's effectiveness in accurately estimating indoor positions, thus contributing to enhanced indoor localization.

Fig. 6 shows the CDF of our proposed solution compared to the research [15]. The results in Fig. 6 clearly indicate that our solution performs significantly better in predicting locations when compared to the reference paper on the same

public dataset and similar situations. Fig. 6 also demonstrates that, for distance errors of two meters or less, our solution achieves an accuracy rate of over 50%, while the research [15] reaches around 30%. These results provide valuable insights into the performance distribution of the solution concerning distance errors. Observing this relationship, it is evident that:

For distance errors less than or equal to 1 meter, the probability of achieving such accuracy is approximately 20%.
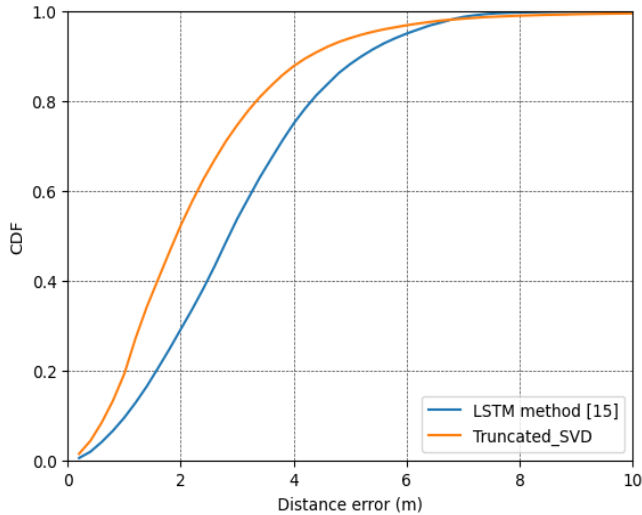


Fig. 6.  CDF of the positioning error distance.

Expanding the acceptable error threshold to two meters significantly increases the probability of success to around 52%.

This visualization is further reinforced by the visual representation in Fig. 7, which vividly illustrates the proportion of predictions falling within different error ranges. It is evident that the proposed solution demonstrates a notable capability in achieving sub-2 meters accuracy, making it suitable for a range of indoor positioning applications. In accordance with the evaluation criteria outlined in Section III(C), the performance metrics for our model are as follows: a Root Mean Square Error (RMSE) stand is 1.97 meters, EDE is 2.23 meters, Mean Squared Error (MSE) is calculated at 3.91 meters, and R-squared ($R^2$) demonstrates a value of 0.69. Additionally, our model shows promising results in terms of error percentages, with 19.41% of errors falling within a 1-meter range and 52.36% within a 2-meter range. The RMSE value is approximately 1.97 meters, indicating a relatively small average deviation between predictions and actual values. This reflects the model's accuracy in estimating positions. The average Euclidean distance is around 2.23 meters, signifying the average difference between predictions and actual values. This is a critical evaluation criterion widely used in location-related tasks. Mean Squared Error (MSE) value is approximately 3.91 meters, representing the average squared error between predictions and actual values. This value indicates the variability of errors and can be used for model comparison. R-squared (R2): The R2 value is approximately 0.69, indicating the model's accuracy in explaining data variance. A high R2 value close to 1 suggests that the model is

reasonably good at explaining the data. Percentage of errors within 1 meter: Around 19.41% of predictions have errors within 1 meter, demonstrating that the model achieves a relatively good level of accuracy in predicting positions with errors less than 1 meter. Percentage of errors within 2 meters: Approximately 52.36% of predictions have errors within 2 meters, which is an acceptable threshold for many real-time applications.
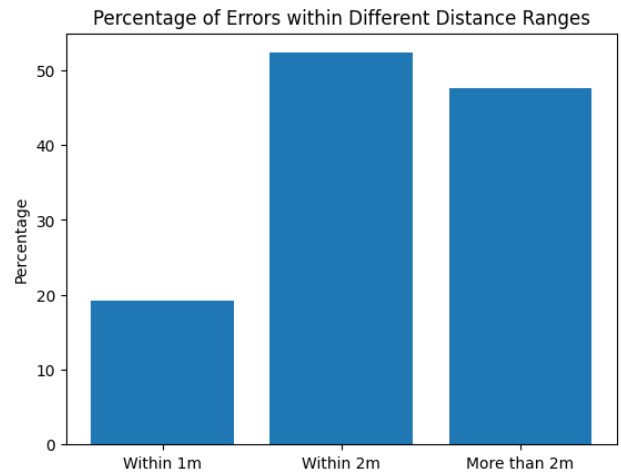


Fig 7. The chart of prediction errors with varying error distances.

In [17], the authors applied deep learning models, specifically RNN/LSTM, to predict indoor positions, achieving accuracy with distance errors ranging from 2.5 meters to 2.7 meters. A significant contribution of our study lies in the substantial enhancement of position prediction accuracy offered by our proposed solution. More precisely, we reduced the error margin from the range of 2.5 meters - 2.7 meters to a mere 2.23 meters, marking a remarkable improvement ranging from 10.8% to 17.4%. The simulation results demonstrate the effectiveness of the Truncated SVD and KNN Regression combination in significantly bolstering position prediction capabilities, particularly in error reduction. Furthermore, our solution also made substantial strides in prediction time efficiency when compared to the findings in reference [17]. As indicated in [17], the training time using the RNN model was 564.1396 seconds, with 10.0848 seconds required for testing. When LSTM was employed, the training process took 581.3599 seconds, and testing consumed 10.1721 seconds. In contrast, our solution demonstrated remarkable efficiency, taking only 4.5523 seconds to complete the same experimental scenario. These results underscore not only the enhancement in accuracy achieved by our approach but also its superior efficiency in prediction time. Additionally, our method simplifies the intricate training process commonly associated with traditional machine learning and deep learning methodologies.

## V. CONCLUSIONS

In conclusion, our study highlights the significant effectiveness of the proposed solution, which combines Truncated Singular Value Decomposition (Truncated SVD) with K-Nearest Neighbors (KNN) regression for indoor positioning. This innovative approach brings about a substantial improvement in prediction accuracy while meeting

real-time requirements. One of the notable advantages lies in the simplicity and efficiency of KNN regression. Unlike traditional machine learning and deep learning solutions that require complex pre-training processes, our method does not burden the user with such complexities. This streamlines the implementation and makes it an attractive choice for various indoor localization scenarios. By integrating Truncated SVD as a dimensionality reduction technique, we enhance the model's robustness and precision. Through rigorous experimentation, we determined that setting Truncated SVD's number of components to 35 minimizes EDEs in predictions, further showcasing the effectiveness of this hybrid approach. This combined methodology not only advances indoor positioning accuracy but also ensures that the solution is practical for real-time applications. In summary, our work presents a powerful and efficient solution for indoor positioning, opening doors to improved location-based services and applications.

## CONFLICTS OF INTEREST

The authors declare no conflict of interest.

## ACKNOWLEDGMENT

## REFERENCES

[1] X. Feng, K. A. Nguyen, Z. J. J. o. I. Luo, and Telecommunication, "A survey of deep learning approaches for WiFi-based indoor positioning," vol. 6, no. 2, pp. 163-216, 2022.

[2] S. A. Zibaei and R. A. Abbaspour, "Evaluation of Improved K-Nearest Neighbors for Indoor Positioning System in Real Complex Buildings," in 2023 9th International Conference on Web Research (ICWR), 2023, pp. 12-19.

[3] X. Zheng, R. Cheng, and Y. Wang, "RSSI-KNN: A RSSI Indoor Localization Approach with KNN," in 2023 IEEE 2nd International Conference on Electrical Engineering, Big Data and Algorithms (EEBDA), 2023, pp. 600-604.

[4] Z. Liu, X. Luo, and T. He, "Indoor positioning system based on the improved W-KNN algorithm," in 2017 IEEE 2nd Advanced Information Technology, Electronic and Automation Control Conference (IAEAC), 2017, pp. 1355-1359.

[5] M. F. Mosleh, R. A. Abd-Alhameed, and O. A. Qasim, "Indoor Positioning Using Adaptive KNN Algorithm Based Fingerprint Technique," in Broadband Communications, Networks, and Systems: 9th International EAI Conference, Broadnets 2018, Faro, Portugal, September 19–20, 2018, Proceedings 9, 2019, pp. 13-21: Springer.

[6] A. Alitaleshi, H. Jazayeriy, and J. J. E. A. o. A. I. Kazemitabar, "EA-CNN: A smart indoor 3D positioning scheme based on Wi-Fi fingerprinting and deep learning," vol. 117, p. 105509, 2023.

[7] S. Tiku, A. Mittal, and S. Pasricha, "A Scalable Framework for Indoor Localization Using Convolutional Neural Networks," in Machine Learning for Indoor Localization and Navigation: Springer, 2023, pp. 159-176.

[8] N. Singh, S. Choe, and R. J. I. A. Punmiya, "Machine learning based indoor localization using Wi-Fi RSSI fingerprints: An overview," vol. 9, pp. 127150-127174, 2021.

[9] M. Ashraf et al., "A Survey on Dimensionality Reduction Techniques for Time-series Data," 2023.

[10] G. E. Hinton and R. R. J. s. Salakhutdinov, "Reducing the dimensionality of data with neural networks," vol. 313, no. 5786, pp. 504-507, 2006.

[11] W.-C. Lu, Y.-C. Cheng, and S.-H. Fang, "A study of singular value decomposition for wireless LAN location fingerprinting," in 2016 IEEE Second International Conference on Multimedia Big Data (BigMM), 2016, pp. 466-470: IEEE.

[12] A. Li, J. Fu, H. Shen, and S. J. I. I. o. T. J. Sun, "A cluster-principal-component-analysis-based indoor positioning algorithm," vol. 8, no. 1, pp. 187-196, 2020.

[13] S.-H. Fang and T. J. I. T. o. M. C. Lin, "Principal component localization in indoor WLAN environments," vol. 11, no. 1, pp. 100-110, 2011.

[14] H. Li, W. Quan, G. Ji, and Z. Qian, "Wireless indoor positioning algorithm based on PCA," in 2015 International Conference on Artificial Intelligence and Industrial Engineering, 2015, pp. 8-9: Atlantis Press.

[15] W. C. Lu, Y. C. Cheng, and S. H. Fang, "A Study of Singular Value Decomposition for Wireless LAN Location Fingerprinting," in 2016 IEEE Second International Conference on Multimedia Big Data (BigMM), 2016, pp. 466-470.

[16] G. M. Mendoza-Silva, P. Richter, J. Torres-Sospedra, E. S. Lohan, and J. J. D. Huerta, "Long-term WiFi fingerprinting dataset for research on robust indoor positioning," vol. 3, no. 1, p. 3, 2018.

[17] H.-Y. Hsieh, S. W. Prakosa, and J.-S. Leu, "Towards the implementation of recurrent neural network schemes for WiFi fingerprint-based indoor positioning," in 2018 IEEE 88th Vehicular Technology Conference (VTC-Fall), 2018, pp. 1-5: IEEE.

# Text Simplification using Hybrid Semantic Compression and Support Vector Machine for Troll Threat Sentences

Juhaida Abu Bakar[1], Nooraini Yusoff[2], Nor Hazlyna Harun[3], Maslinda Mohd Nadzir[4], Salehah Omar[5]

Data Science Research Lab, School of Computing, Universiti Utara Malaysia, Kedah, Malaysia[1, 3, 4]
Faculty of Data Science and Computing, Universiti Malaysia Kelantan, Kota Bharu, Kelantan, Malaysia[2]
Department of Information Technology and Communication, Sultan Abdul Halim Mu'adzam Shah Polytechnic, Kedah, Malaysia[5]

*Abstract*—Text Simplification (TS) is an emerging field in Natural Language Processing (NLP) that aims to make complex text more accessible. However, there is limited research on TS in the Malay language, known as Bahasa Malaysia, which is widely spoken in Southeast Asia. The challenges in this domain revolve around data availability, feature engineering, and the suitability of methods for text simplification. Previous studies predominantly employed single methods such as semantic compression, or machine learning with the Support Vector Machine (SVM) classifier consistently achieving an accuracy of approximately 70% in identifying troll sentences—statements containing threats from online trolls notorious for their disruptive online behavior. This study combines semantic compression and machine learning methods across lexical, syntactic, and semantic levels, utilizing frequency dictionaries as semantic features. Support Vector Machine and Decision Tree classifiers are applied and tested on 6,836 datasets, divided into training and testing sets. When comparing SVM and Decision Tree with and without semantic features, SVM with semantics achieves an average accuracy of 92.37%, while Decision Tree with semantics reaches 91.21%. The proposed TS method is evaluated on troll sentences, which are often associated with cyberbullying. Furthermore, it is worth noting that cyberbullying has been reported to be a significant issue, with Malaysia ranking as the second worst out of the 28 countries surveyed in Asia. Therefore, the outcomes of the study could potentially offer means, such as machine translation and relation extraction, to help prevent cyberbullying in Malaysia.

*Keywords—Text simplification; semantic compression; machine learning; natural language processing; cyber bullying*

## I. INTRODUCTION

Natural Language Processing (NLP) represents a branch of artificial intelligence dedicated to enabling both machines and humans to comprehend, interpret, and deduce significance from human languages [1]. In the contemporary landscape, NLP encounters its most noteworthy challenges in the complexity of human communication. The process of deciphering and manipulating language is highly intricate, hence the common practice of employing diverse techniques to address a multitude of challenges.

This area of research encompasses numerous expanding and valuable applications. Natural Language Processing (NLP) encompasses a wide spectrum of tasks, ranging from straightforward ones like spell checking, keyword search, synonym identification, data extraction, classification, summarization, and text simplification, to more complex tasks like machine translation. In the future, NLP holds the potential to revolutionize task assistance. In this chapter, we will delve into past research related to a specific NLP task—text simplification.

Text simplification involves the transformation of a sentence into one or more straightforward sentences, making it more understandable for both machines and humans while preserving the original context and content. Additionally, text simplification serves as a valuable application that can improve various Natural Language Processing (NLP) tasks. Study by [2] highlights that text simplification tasks encompass several operations, including theoretical simplification to streamline content and structure, elaborate modification to clarify key points, and text summarization to remove peripheral or irrelevant information. The primary goal of text simplification is to enhance the accessibility of information for individuals with disabilities [3-4], those with low literacy levels [5-6], and non-native speakers [7].

In the Malay language, the exploration of text simplification is a relatively new area of study. Recent years have witnessed extensive research in Malay language studies, particularly in the domains of text summarization and sentence compression [8-11]. Researchers have been keen on enhancing the quality and cohesiveness of generated summaries. Sentence compression, a technique that involves eliminating non-essential details while preserving sentence grammar patterns, has garnered significant attention. This process identifies and removes frequently occurring sequences of adjacent words across a collection of documents, resulting in heuristic knowledge for sentence compression with an 85% confidence value [8].

Study by [8] primarily focuses on the Frequent Pattern growth tree, which stores compressed and critical information related to frequent patterns in large databases. However, it's worth noting that this study of text summarization does not encompass semantic compression, potentially leading to issues of ambiguity. Existing literature suggests that Malay language studies primarily concentrate on text summarization, specifically sentence compression, without delving into semantic comprehension. Fig. 1 illustrates the distinction between text simplification and text summarization.

---

***Example sentence:***
Google began in January 1996, as a research project by Larry Page, who was soon joined by Sergey Brin, when were both PhD students at Stanford University in California.
text simplification:
Google **was started** in January 1996, as a research project by Larry Page, who was soon joined by **and** Sergey Brin, when were both **two** PhD students at Stanford University in California, **USA**.
text summarization:
Google began in January 1996, as a research project by Larry Page, who was soon joined by Sergey Brin, when were both PhD students at Stanford University in California.

Fig. 1. Text simplification versus text summarization [31].

In Text Simplification (TS), information extraction stands as a pivotal phase. The primary output of the information extraction process is the Syntax Tree, which illustrates the sentence's structure [12]. However, the syntax tree can become ambiguous when a sentence adheres to multiple grammar rules. To address this issue, machine learning techniques are commonly employed. These methods encompass Support Vector Machine (SVM) (e.g., [13-14]), Maximum Entropy (e.g., [15]), Decision Tree (DT) (e.g., [16]), and Conditional Random Field (e.g., [17]).

Among these techniques, the Support Vector Machine (SVM) has been recognized as the most effective classifier for text simplification, achieving an accuracy of approximately 70% [18]. It is important to note that studies employing SVM for text simplification have predominantly concentrated on the English language. In contrast, there is a lack of research on text simplification in the Malay language.

Furthermore, within the domain of Text Simplification, the primary objective is to condense a given sentence. This task necessitates a process of comprehending the inherent meaning of the sentence, commonly referred to as semantic compression.

In many text simplification approaches, a singular method is typically employed, whether it's a machine learning method or semantic compression. Studies solely focused on machine learning methods tend to overlook the significance of sentence structure properties crucial for semantic interpretation. Conversely, research exclusively centered on semantic compression may encounter challenges in predicting syntax trees, leading to potential ambiguity problems. Therefore, there is a growing recognition of the necessity to combine machine learning methods and semantic compression. In this hybrid approach, machine learning is applied to identify ambiguous sentence structures, while semantic compression is employed to simplify sentences based on relevant semantic content.

Troll is a prime example necessitating text simplification, as it often comprises sentences laden with concealed meanings. Originally, trolling involved the use of deceptive posts as bait to elicit responses from other online community members, often luring them into engaging with a fabricated story. Trolling encompasses various forms, and the term "trolling" has been broadly applied to describe various malicious or harassing activities on the internet. These activities may include instigating contentious discussions, targeting individuals or groups with harassment, sharing offensive content, vandalizing community-contributed pages, defacing memorial pages, and even being used interchangeably with cyberbullying. As a result, this study focuses on trolls associated with cyberbullying as the domain for testing a proposed text simplification method.

The motivation by engaging in TS research in a minority language offers the opportunity to develop language-specific techniques and tools, enriching the broader NLP field while deepening insights into the unique linguistic features and challenges of that language. This paper introduces a hybrid approach for text simplification in the Malay language. The model effectively distinguishes between complex and non-complex words, offering a potential solution to combat cyberbullying in Malaysia through means like machine translation and relation extraction. The key steps involve developing text simplification features that emphasize semantic aspects. Additionally, lexical features, including stemmed words, are incorporated into the study. Subsequently, hand-crafted features encompassing lexical, syntactic, and semantic attributes are organized and classified using machine learning techniques to attain the highest accuracy results.

## II. RELATED WORKS

The NLP components employed in TS encompass five levels: lexical, syntactic, semantic, discourse, and pragmatic. According to [19], the TS process primarily involves the lexical and syntactic levels. However, it's worth noting that semantic considerations play a crucial role in both the lexical and syntactic approaches to ensure the preservation of word and sentence meanings.

The lexical level, referred to as lexical simplification (LS), concentrates on replacing complex words with simpler synonyms. For instance, it involves substituting "facile" with "easy." Previous research in psycholinguistics has shown that such substitutions of complex terms within a sentence, as done by comprehensive lexical simplification, have significant potential to enhance sentence readability [20]. LS involves altering the intricate or unusual phrasing within a sentence by replacing it with a synonymous word that is more straightforward and comprehensible [21].

In the realm of syntactic simplification, it encompasses distinct elements like idiomatic phrases, apposition, coordination, subordination, and voice. Study by [22] employ the typed dependency representations provided by the Stanford Parser. They argue that these formatted dependencies offer a high level of precision, facilitating the creation of straightforward standards and the automation of corporate acquisition processes.

Recent research demonstrates that the semantic approach has been applied in text simplification tasks, as evidenced by studies such as [22-27]. Study by [28] also highlights that

semantic compression can serve as a valuable technique for intelligently generalizing terms while minimizing information loss. To address structural mismatches, study by [29] suggests employing semantic parsing to rephrase sentences.

There are various approaches employed for text simplification (TS) tasks. Recent research has shown a growing interest in hybrid approaches that integrate multiple techniques for simplification such as deep semantic and monolingual machine translation have been combined in the hybrid approach, as demonstrated by [30], structural semantics and neural methods are another focus in recent studies, exemplified by [27], hybrid approaches may involve a combination of hand-crafted transformation rules, machine learning (ML) techniques, and semantic parsers, as explored by [31], these hybrid approaches often merge natural language processing (NLP) components with machine learning techniques. The research conducted by [20] advocate for the use of Machine Learning (ML) techniques as a means to achieve more reliable solutions in text simplification. These hybrid methods represent a multifaceted approach to text simplification, leveraging various techniques to enhance the quality and effectiveness of simplification processes.

As a relatively new language within the field of text simplification, a more comprehensive investigation of each feature is essential to achieve higher accuracy. The study in [32] involved the utilization of all relevant features, with a subsequent comparison of results to identify the most effective features for future use. Thus, the primary objective of this study is to combine the strengths of semantic compression and machine learning methods through hybridization. This approach aims to leverage the benefits of both techniques to enhance the practice of text simplification.

## III. METHODOLOGY

The research methodology of the study can be segmented into five distinct phases: a literature review phase, a phase dedicated to defining data sets and specifications, a phase focused on designing text simplification features for the TS model, a phase involving the construction of the TS model based on SVM classifier and selected features, and finally, a phase dedicated to performance evaluation.

### A. Datasets

In this study, the primary data sources include news articles, online resources, and existing datasets for the Malay language. Additionally, a corpus from previous studies, including [33-36], covering Parts of Speech (POS) and Noun Phrases, was used to create the Malay Text Simplification Dataset (Malay TS Dataset) with 6,836 instances categorized as complex or non-complex.

The work begins by utilizing the state-of-the-art corpus developed by [34], known as the Malay corpus. This corpus comprises 18,387 tokens, each of which is accompanied by word category information and is written using the Rumi script. It includes 21 word categories for part-of-speech (POS) tagging, following the standard provided by the Dewan Bahasa dan Pustaka (DBP). You can find the Malay part-of-speech tagset within the corpus in Table I.

TABLE I. PART-OF-SPEECH DBP TAGSET IN MALAY CORPUS [34]

| Tag Set | Description | Example in Malay language with English gloss | Number of tokens |
|---|---|---|---|
| KN | Noun | chair (*kerusi*) | 6108 |
| KK | Verb | eat (*makan*) | 2539 |
| ADJ | Adjective | black, beautiful, deep (*hitam, cantik, dalam*) | 1623 |
| KSN | Preposition | at, to, from, to (*di,ke, dari, kepada*) | 1409 |
| KB | Auxiliary verb | will, not yet, can (*akan, belum, boleh*) | 390 |
| KG | Pronoun | me, you (*saya, awak*) | 496 |
| KH | Conjunction | which, and, or (*yang, dan, atau*) | 1608 |
| ADV | Adverb | perhaps (*bahasawanya, barangkali*) | 817 |
| KT | Question | what, how much (*apa, berapa*) | 49 |
| KBIL | Cardinal | one, two (*satu, dua*) | 258 |
| KPM | Narrator | is (*adalah, ialah*) | 100 |
| KP | Command | don't, please (*jangan, sila*) | 5 |
| KAR | Direction | in, up, down (*dalam, atas, bawah*) | 48 |
| PW | Discourse mark | even, then (*hatta, maka*) | 9 |
| KEP | Short form | *UNCR, PBB* | 179 |
| #E | Clitic *lah* | try it (*cubalah*) | 31 |
| KN@ | Clitic *nya* | His/her book (*Bukunya*) | 235 |
| KNF | Deny | No, it's not (*tidak, bukan*) | 171 |
| KNK | Proper noun | *Allah, Muhammad* | 236 |
| SEN | List number | *(i), (ii), (iii), etc* | 3 |
| SYM | Any symbol or punctuations | *. , " - + etc* | 2073 |

The study in [37] established a process for identifying complex words in three languages. This study follows the same process developed by Yimam, known as Complex Word Identification (CWI). In this process, a survey was conducted using 10 TS control samples and 10 TS non-control samples from the Malay corpus. For instance, the study focuses on TS users, who are non-native speakers. Therefore, 10 non-native speakers of the language were selected as a control sample, along with 10 native speakers. Native speakers are individuals who learned their first language in childhood, often referred to as their mother tongue [38]. Non-natives are individuals who learned a different language as their first language in childhood. Respondents were provided with texts from the Malay corpus and asked to annotate each word based on its complexity.

The results of the answers provided by the 10 native speakers and the 10 non-native speakers will determine whether a word is classified as complex or not. The label assigned to the target word is based on the responses of these 10 native and 10 non-native speakers. If at least one annotator marks the word as complex, the label will be "COMPLEX" (1); otherwise, it will be "NOT COMPLEX" (0).

Afterward, data cleaning is an integral part of this study, which involves removing punctuation and converting all letters to lowercase. This is done to address data sparsity within the dataset. The dataset comprises original sentences, target word indices, counts of annotations by native and non-native speakers for the sentences, counts of markings by native and non-native speakers for the target words, and binary and classification labels for the target words. Subsequently, a dataset consisting of 6,836 instances with labels indicating complexity or non-complexity is created. The detailed description of the Malay TS Dataset, including complexity information after data cleaning, is provided in Table II.

TABLE II.    PART-OF-SPEECH DBP TAGSET IN MALAY TS DATASET WITH THE COMPLEX INFORMATION

| Tag Set | Description | Number of tokens | Complex word | Non-complex word |
|---------|-------------|------------------|--------------|------------------|
| KN | Noun | 2459 | 299 | 2160 |
| KK | Verb | 1103 | 88 | 1015 |
| ADJ | Adjective | 687 | 82 | 605 |
| KSN | Preposition | 591 | 3 | 588 |
| KB | Auxiliary verb | 136 | 1 | 135 |
| KG | Pronoun | 210 | 6 | 204 |
| KH | Conjunction | 735 | 14 | 721 |
| ADV | Adverb | 332 | 12 | 320 |
| KT | Question | 22 | 2 | 20 |
| KBIL | Cardinal | 112 | 2 | 110 |
| KPM | Narrator | *None* | *None* | *None* |
| KP | Command | *None* | *None* | *None* |
| KAR | Direction | *None* | *None* | *None* |
| PW | Discourse mark | *None* | *None* | *None* |
| KEP | Short form | 6 | 6 | 0 |
| #E | Clitic *lah* | 1 | 1 | 0 |
| KN@ | Clitic *nya* | 10 | 10 | 0 |
| KNF | Deny | *None* | *None* | *None* |
| KNK | Proper noun | 3 | 3 | 0 |
| SEN | List number | *None* | *None* | *None* |
| SYM | Any symbol or punctuations | *None* | *None* | *None* |

## B. Proposed Method

Generally, the method begins by importing the raw Malay text dataset. The proposed approach encompasses three stages before obtaining the output of text simplification. Initially, the raw Malay text Part-of-Speech (POS) dataset is converted into feature extractions. Two types of feature extractions are employed: semantic compression features and lexical features. Text compression is achieved by using a semantic network and information on term frequencies from a frequency

dictionary. Subsequently, lexical features are constructed based on Part-of-Speech (syntactic), vowels (lexical), characters (lexical), and syllables (lexical). Handcrafted features combine semantic compression and lexical features. Finally, machine learning classifiers, specifically Decision Tree (DT) and Support Vector Machines (SVM), are used to identify complexity patterns in the Malay language. This hybrid method is configured for these two machine learning classifiers using the frequency dictionary. Additionally, the study evaluates this method on previously unseen troll sentences. Fig. 2 illustrates the proposed method during this phase.
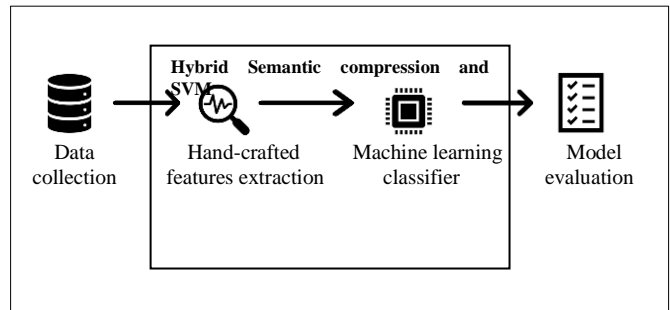


Fig. 2.   Proposed method.

This phase assessed the validity of the hypotheses derived from the literature review. It primarily involved the preparation and development of lexical, syntactic and semantic features based on the findings from the preceding step. The experimental aspect of this phase focused on extracting features related to factors like length, frequency, lexical, syntactic, and semantic characteristics. Additionally, base words in the Malay language were extracted and incorporated as features. The Part-of-Speech (POS) tags present in the Malay corpus were also employed as syntactic features. To align with semantic requirements, a frequency dictionary was generated. The lexical features, as presented in Table III, were ultimately adopted for this study. Subsequently, each feature in token form underwent a normalization process to facilitate the development of learning models based on Decision Trees (DT) and Support Vector Machine (SVM) classifiers.

TABLE III.    LEXICAL, SYNTACTIC AND SEMANTIC FEATURES IN MALAY TS DATASET

| Type | Features | Abbreviation |
|------|----------|--------------|
| Lexical | Number of syllables | SYL |
| | Length of word | CHAR |
| | Base word | STEM |
| | Frequency of word | FREQ |
| | Number of token (not stem) | VOW |
| | Number of token (after stem) | Vow |
| Syntactic | Part-of-speech  Tagging | POS |
| Semantic | Frequency dictionary | DF |

Algorithm 1 outlines the features for constructing the Malay TS method for the Malay language.

| **Algorithm 1:** Malay TS method |
|---|
| 1: Input: text T, word_feature W, gaps G, discard_empty D, flags F |
| 2: read T sequence, |
|    read word_feature W, |
|    *feature_type1*: Syllable feature, |
|    *feature_type2*: Character feature, |
|    *feature_type3*: Stem feature, |
|    *feature_type4*: Frequency feature, |
|    *feature_type5*: Part-of-Speech tag feature, |
|    *feature_type6*: Vowel feature, |
|    *feature_type7*: Frequency distribution feature, |
|    read gaps G, read discard_empty D, read flags F, |
| 3: If feature_type3 exists in T sequence |
| 4:  Enhance with the modification rules and steps |
| 5:   If not |
| 6:       Continue to machine learning algorithms (SVM, DT) |
| 7:   Fit to gaps G, discard_empty D, flags F |

As a result of the above works, two classifiers were utilized, specifically the SVM and DT classifiers. The experiment is partitioned into two segments: one that takes semantic features into account and one that does not take semantic features. Data was divided using k-fold cross-validation (k=10), and subsequently, the average outcomes are computed. These results will be analyzed and discussed in the Experiment and Results section.

*C. Performance Evaluation*

In the domain of machine learning, particularly in the context of statistical classification, a confusion matrix, alternatively referred to as an error matrix, is a structured table format that provides a means to visually assess the effectiveness of an algorithm, often in the context of supervised learning. Fig. 3 illustrates the configuration of the confusion matrix. Its primary purpose is to evaluate the performance of a classification algorithm. In this study, four metrics were employed: accuracy, precision, recall, and F1-measures, to gauge the performance of the classification algorithm.



Fig. 3.   Confusion matrix.

## IV.   EXPERIMENTS AND RESULTS

The hybrid method proposed in this study was employed on a dataset comprising 6,836 instances. This original dataset encompasses lexical details, syntactic information, sentences, base words, and semantic information, as illustrated in Table IV.

TABLE IV.   FEATURE ENGINEERING FOR MALAY TS DATASET

| POS | CHAR | VOL | SYL | Sentence | STEM | DF | Vow | Binary | Class |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 4 | 2 | 2 | Asid Alfa Li | asid | 4 | 2 | 1 | Complex |
| 1 | 4 | 2 | 2 | Asid Alfa Li | alfa | 3 | 2 | 1 | Complex |
| 1 | 6 | 3 | 3 | Asid Alfa Li | lipoik | 3 | 3 | 1 | Complex |
| 1 | 7 | 3 | 3 | Asid Alfa Li | manfaat | 3 | 3 | 1 | Complex |
| 2 | 5 | 2 | 2 | Asid Alfa Li | untuk | 73 | 2 | 0 | Not complex |
| 1 | 5 | 2 | 2 | Asid Alfa Li | saraf | 13 | 2 | 0 | Complex |
| 3 | 4 | 2 | 2 | Saya menga | saya | 9 | 2 | 1 | Complex |

Subsequently, a frequency dictionary and vowel characteristics dictionary are constructed for base words, contributing to the generation of semantic features. The frequency dictionary tallies the occurrences of base words within the corpus, while the vowel characteristics dictionary calculates the count of vowels in each base word. The POS features encompass a set of 31 labels, including nouns, prepositions, pronouns, verbs, denies, and more, as shown in Table V. The stem feature is then removed from the final dataset, leaving the DF (frequency dictionary) and Vow (vowel characteristics) features as representations of the stem word, as illustrated in Table VI.

TABLE V.   PART OF SPEECH FEATURES WITH 31 LABELS

| Tagset | Labeling | Numbering |
|---|---|---|
| Noun | kn | 1 |
| Preposition | ksn | 2 |
| Pronoun | kg | 3 |
| Verb | kk | 4 |
| Deny | knf | 5 |
| Conjunction | kh | 6 |
| Adjective | adj | 7 |
| Adverb | adv | 8 |
| Question word | kt | 9 |
| Verb with clitics -nya | kk@ | 10 |
| Auxiliary verb | kb | 11 |
| Narrator | kpm | 12 |
| Short form | kep | 13 |
| Cardinal | kbil | 14 |
| Proper noun | knk | 15 |
| Noun with clitic -lah | kn# | 16 |
| Adjective with clitics -nya | adj@ | 17 |
| Adverb with clitics -nya | adv@ | 18 |
| Pronoun with clitics -lah | kg# | 19 |
| Noun with clitics -nya | kn@ | 20 |
| Verb with clitics -lah | kk# | 21 |

| Tagset | Labeling | Numbering |
|---|---|---|
| Direction | kar | 22 |
| Command | kp | 23 |
| List number | sen | 24 |
| Adjective with clitics -lah | adj# | 25 |
| Auxiliary verb with clitics -lah | kb# | 26 |
| Adverb with clitics -lah | adv# | 27 |
| Pronoun with clitics -nya | kg@ | 28 |
| Explanation word | kkt | 29 |
| Deny with clitics -lah | knf# | 30 |
| Deny with clitics -nya | knf@ | 31 |

TABLE VI.    FEATURE ENGINEERING FOR MALAY TS DATASET WITH SEMANTIC FEATURE

| POS | CHAR | VOW | SYL | DF | Vow | Class |
|---|---|---|---|---|---|---|
| 1 | 4 | 2 | 2 | 4 | 2 | Complex |
| 1 | 4 | 2 | 2 | 3 | 2 | Complex |
| 1 | 6 | 3 | 3 | 3 | 3 | Complex |
| 1 | 7 | 3 | 3 | 3 | 3 | Complex |
| 2 | 5 | 2 | 2 | 73 | 2 | Not complex |
| 1 | 5 | 2 | 2 | 13 | 2 | Complex |
| 3 | 4 | 2 | 2 | 9 | 2 | Complex |

In the realm of machine learning, data normalization is employed to reduce the impact of feature scales on model training. The preparation of data for machine learning in this study involves the utilization of numerical data, ensuring that our model converges to optimal weights and, ultimately, resulting in a more precise model. To achieve this, min-max normalization has been implemented. Regarding class labels, they are assigned values of 0 (indicating simplicity or non-complexity) or 1 (indicating complexity), as illustrated in Table VII. Subsequently, the dataset has been divided into training and testing sets using a 10-fold cross-validation approach, denoted as Tr:Te dataset.

TABLE VII.    DATA AFTER NORMALIZATION PROCESS

| | 0 | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|---|
| 0 | 0.000 | 0.1667 | 0.250 | 0.086957 | 0.010714 | 0.33333 | 1.0 |
| 1 | 0.000 | 0.1667 | 0.250 | 0.086957 | 0.007143 | 0.33333 | 1.0 |
| 2 | 0.000 | 0.2778 | 0.375 | 0.130435 | 0.007143 | 0.50000 | 1.0 |
| 3 | 0.000 | 0.3333 | 0.375 | 0.130435 | 0.007143 | 0.50000 | 1.0 |
| 4 | 0.033 | 0.2222 | 0.250 | 0.086957 | 0.257143 | 0.33333 | 0.0 |

The learning process is subsequently executed using DT and SVM classifiers. To ensure a robust evaluation, the dataset has been split into an 80% training set and a 20% testing set, denoted as 80Tra:20Test. For the SVM classifier, the RBF kernel and class weighting have been applied, particularly beneficial for handling imbalanced datasets. Following the completion of the experiment table containing

semantic features, the most effective classifier was determined. This optimal classifier is then saved as a "pickle" file, enabling it to be used for testing new data. In the context of this study, the aim is to classify troll data as either complex or non-complex.

After completing the feature engineering process, the training datasets undergo several performance evaluations. Two algorithms are employed to predict text simplification, distinguishing between complex and non-complex words. To ensure the suitability of the chosen model, a score test model is utilized. The algorithms in use are Decision Tree classifiers and Support Vector Machine (SVM). The modeling is implemented in a Jupyter notebook using Python code, and both datasets, one with semantic features and one without, are tested. The Decision Tree classifier achieves its highest accuracy of 92.98% when using semantic feature information. On the other hand, the SVM achieves its highest accuracy of 93.20% with or without the semantic feature information. This suggests that semantic features may or may not be necessary for the SVM classifier, but there is a significant difference for the Decision Tree classifiers.

The average accuracy of both classifiers indicates that SVM outperforms the DT classifier by a margin of 0.6%. Table VIII provides a performance comparison between the two classifiers, revealing that the frequency dictionary does not significantly impact the results. Both cases, with and without a frequency dictionary, yield similar accuracy levels. The presence or absence of the frequency dictionary doesn't result in a noticeable difference in average accuracy in this experiment.

However, when examining each production of the classifier model individually, the significance of semantic features in the training dataset becomes evident. Table IX and Table X present precision, recall, and F1-score for the best models of SVM and DT, respectively, highlighting the importance of semantic features in improving these metrics.

TABLE VIII.    PERFORMANCE OF TWO CLASSIFIERS WITH TWO DIFFERENCE FEATURES

| Data Split / ML classifier | Frequency distribution | | | |
|---|---|---|---|---|
| | *With frequency distribution* | | *Without frequency distribution* | |
| | DT (%) | SVM (%) | DT (%) | SVM (%) |
| 90Tr:10Te | **92.98** | 92.40 | 92.69 | 92.40 |
| 80Tr:20Te | 92.62 | **93.20** | 92.91 | **93.20** |
| 70Tr:30Te | 91.96 | 92.30 | 91.61 | 92.30 |
| 60Tr:40Te | 91.15 | 92.07 | 91.55 | 92.07 |
| 50Tr:50Te | 90.46 | 92.22 | 91.72 | 92.22 |
| 40Tr:60Te | 90.59 | 92.52 | 91.83 | 92.52 |
| 30Tr:70Te | 90.76 | 92.35 | 91.98 | 92.35 |
| 20Tr:80Te | 89.78 | 92.10 | 91.17 | 92.10 |
| 10Tr:90Te | 90.56 | 92.17 | 90.44 | 92.17 |
| Average | 91.21 | **92.37** | 91.77 | **92.37** |

TABLE IX.     SVM LEARNING MODEL

|  | Precision (%) | Recall (%) | F1-score (%) | Support |
|---|---|---|---|---|
| 0 | 94 | 100 | 97 | 1279 |
| 1 | 50 | 3 | 6 | 89 |
| accuracy |  |  | 93 | 1368 |
| macro avg | 72 | 52 | 51 | 1368 |
| weighted avg | 91 | 93 | 91 | 1368 |
| 0 | 94 | 100 | 97 | 1279 |

TABLE X.     DT LEARNING MODEL

|  | Precision (%) | Recall (%) | F1-score (%) | Support |
|---|---|---|---|---|
| 0 | 94 | 98 | 96 | 632 |
| 1 | 58 | 27 | 37 | 52 |
| accuracy |  |  | 93 | 684 |
| macro avg | 76 | 63 | 67 | 684 |
| weighted avg | 92 | 93 | 92 | 684 |
| 0 | 94 | 98 | 96 | 632 |

The top-performing model from the Malay TS Dataset, as determined by the research conducted by [40], is utilized to categorize unannotated troll threat sentences. The research materials comprise vlogs, which are video content sourced from the YouTube platform. The study scrutinizes 30 videos recorded by Mat Luthfi between 2011 and 2014. This investigation delves into the use of sarcastic language in YouTube videos, utilizing modern technology as the primary medium of contemporary society. Sarcasm is the examination of employing irony to ridicule or express disdain. On the other hand, "trolling" refers to a predominantly indirect form of communication. The term "trolling" is widely used to describe various malicious or harassing activities on the internet, such as initiating inflammatory discussions, among others, as noted by [39]. To the best of the researcher's knowledge, there is no publicly accessible Malay language troll dataset, so the work by [40], which examines sarcasm, serves as a suitable substitute for a troll dataset.

Before classifying unannotated troll threat sentences as either complex or non-complex words, these sentences (unseen data) must undergo a feature extraction process. This study investigates three different types of sarcasm: Irony Sarcasm, Sarcastic Sarcasm, and Sinise Sarcasm. There are 173 instances in 11 scripts for Irony Sarcasm, 101 instances in seven scripts for Sarcastic Sarcasm, and 303 instances in 10 scripts for Sinise Sarcasm, totaling 578 instances used for testing the Malay TS model.

The initial step involves data cleaning, which includes removing punctuation, converting words to lowercase, and applying the stemming process. Subsequently, a Malay Part-of-Speech tagging system, developed based on the ID3 algorithm by [41], is employed. Table XI provides an overview of the unseen dataset and its preparation process.

TABLE XI.     UNSEEN DATASET

| INPUT | POS | CHAR | VOW | SYL | STEM | DF | Vow |
|---|---|---|---|---|---|---|---|
| *Test* | 4 | 4 | 1 | 1 | *test* | 1 | 1 |
| *Ke* | 2 | 2 | 1 | 1 | *ke* | 1 | 1 |
| *Facebook* | 1 | 8 | 4 | 2 | *facebook* | 1 | 4 |
| *Dalam* | 2 | 5 | 2 | 2 | *dalam* | 2 | 2 |
| *hidup* | 4 | 5 | 2 | 2 | *hidup* | 1 | 2 |
| *aku* | 3 | 3 | 2 | 2 | *aku* | 3 | 2 |
| *tak* | 5 | 3 | 1 | 1 | *tidak* | 13 | 2 |
| *da* | 4 | 2 | 1 | 1 | *ada* | 8 | 2 |
| *sapa-sapa* | 9 | 9 | 4 | 4 | *siapa* | 1 | 3 |

Table XII displays the proportions of complex and non-complex sentences in the troll threat dataset. Language experts have thoroughly evaluated the test results on these troll threat sentences. Table XIII presents the marks assigned by expert analysts to each test data sample generated by the Malay TS model.

TABLE XII.     PROPORTION OF COMPLEX AND NON-COMPLEX TROLL SENTENCE

| Sarcasm types | Non-complex | Complex |
|---|---|---|
| Irony | 151 | 22 |
| Sarcastic | 88 | 13 |
| Sinise | 284 | 19 |

TABLE XIII.     EXPERT RESULT FOR TROLL SENTENCE BASED ON SVM

| Test sample | Irony | Sarcastic | Sinise |
|---|---|---|---|
| Total token | 173 | 101 | 303 |
| Token wrongly label | 22 | 13 | 19 |
| Token correctly label | 151 | 88 | 284 |
| Accuracy (%) | 87.28 | 87.13 | 93.73 |
| Average accuracy (%) | **89.38** | | |

As indicated in Table XIII, the SVM model effectively recognizes only non-complex words. It encountered difficulties in identifying complex words within this unseen dataset, resulting in a low success rate for complex words. When testing with unseen data using SVM, it shows that there are no instances of Type II errors, but Type I errors are present. The SVM model struggles to predict the complex class in three separate unseen datasets.

According to Table XIV, the Decision Tree (DT) model demonstrates success in identifying both non-complex and complex words. However, it occasionally misclassifies words, leading to a lower accuracy percentage compared to the SVM model. Testing on the unseen data reveals the presence of both Type I and Type II errors in the predictions made by the DT model. Notably, the DT model can predict complex classes in the Sarcastic and Sinise datasets, although the number of accurate predictions in these cases is relatively small.

TABLE XIV.    EXPERT RESULT FOR TROLL SENTENCE BASED ON DT

| Test sample | Irony | Sarcastic | Sinise |
|---|---|---|---|
| Total token | 173 | 101 | 303 |
| Token wrongly label | 41 | 11 | 26 |
| Token correctly label | 132 | 90 | 277 |
| Accuracy (%) | 76.30 | 89.11 | 91.42 |
| Average accuracy (%) | **85.61** | | |

## V.    DISCUSSIONS

In this project, a novel dataset called the Malay TS Dataset has been introduced. Additionally, a new Malay TS method has been developed by integrating three levels of NLP components with ML classifiers. The proposed method combines lexical, syntactic, and semantic features with an SVM classifier. To assess the classifier model, a comparison has been made between SVM and DT classifiers, and the findings of this comparative study are presented.

Based on the readings, the SVM classifier exhibits the highest accuracy in identifying troll sentences. The experiment involved utilizing K-fold cross-validation to split the data. To assess the method's effectiveness, the outcomes of the proposed approach were compared with another classifier, specifically DT. The proposed approach demonstrates promising results with a robust classifier model. The findings indicate that the SVM classifier, utilizing an 80-20 split of training and test data, performs as the best classifier model. However, when applied to troll data, the developed SVM model struggles to predict complex words. In contrast, the DT model, while encountering fewer complex words, exhibits better performance in predicting them.

In this research, an automated Malay TS model has been successfully developed. A novel approach, referred to as the Hybrid Semantic Compression-SVM method, has been introduced. This method aims to identify complex words within text. The research utilizes a dataset extracted from the Malay corpus by [33], containing a total of 6,836 instances. Previous studies have typically employed these two methods independently, while this study seeks to combine them for enhanced accuracy. The primary objective of this research is to hybridize semantic compression and Support Vector Machine to enhance text simplification performance. This overarching goal is complemented by three sub-objectives. Firstly, the creation of a Malay TS lexical dataset is undertaken. Secondly, the design of text simplification features for the TS model is carried out, drawing from prior work by [42]. Lastly, the results of the proposed method are evaluated against an existing Python-based classifier.

## VI.    CONCLUSION

Text simplification is a subfield of NLP that has seen significant development in recent years. While research in English has been extensive, tackling simplified text in other languages presents challenges due to limited resources and associated data. This study focuses on analyzing lexical, syntactic, and semantic features to identify troll threat sentences in the Malay language, and the development of resources marks the beginning of this effort.

In summary, this study exclusively incorporates frequency dictionary features within the semantic compression method. Looking ahead, there are several avenues for enhancing this project. Malay, being a minority language, has limited potential for leveraging semantic information. Semantic compression is a component of semantic analysis and comprises two crucial stages: the frequency dictionary and the semantic network. In this research, to the best of our knowledge, only the frequency dictionary has been implemented, as the code is available for development alongside existing features (lexical and syntactic). However, due to the constraints in accessing tools freely for building syntactic information based on dependencies and constituent trees, the discussion of semantic networks is omitted in this study.

To enhance the application of this project, it can be extended with three additional stages in the development of Complex Word Identification (CWI). These stages encompass Substitution Generation, Substitution Selection, and Substitution Ranking, constituting the second, third, and fourth steps in CWI. The second step involves generating potential substitutions for the target words identified in the initial step. Subsequently, the system selects the most appropriate replacement, and the final step entails organizing the hierarchy of replacement options that can be applied to the previously identified target word.

Exploring higher-level Natural Language Processing (NLP) components, such as syntactic analysis, proves more suitable for analyzing social media data compared to mere word-level comprehension. Lexical feature analysis, on the other hand, aligns better with users facing language difficulties (e.g., dyslexia, aphasia) and non-native speakers. Investigating patterns in troll sentences as compared to standard Malay sentences could yield valuable insights if developed further.

Social network datasets necessitate a distinct approach from conventional language sentences. There are additional preprocessing steps required to analyze such data effectively. Handling text abbreviations, dialects, slang, and other variations is essential before arriving at the base words within the text. Techniques like lemmatization are more appropriate for word recognition than stemming. Furthermore, resources like WordNet Bahasa should be considered in this analysis. A comprehensive study integrating social network analysis and data analytics is essential for identifying troll threat sentences.

### REFERENCES

[1]   M. J. Garbade, "A Simple introduction to Natural Language Processing," Becoming Human: Artificial Intelligent Magazine, 2018.

[2] A. Siddharthan, "A survey of research on text simplification," ITL - International Journal of Applied Linguistics, 165, pp. 259-298, 2014.

[3] Y. Canning, J. Tait, J. Archibald, and R. Crawley, "Cohesive generation of syntactically simplified newspaper text," In Proceedings of the Third International Workshop on Text, Speech and Dialogue (TSD), 2000.

[4] K. Inui, A. Fujita, T. Takahashi, R. Iida, and T. Iwakura, "Text simplification for reading assistance: A project note," In Proceedings of the 2nd International Workshop on Paraphrasing, 2003.

[5] W. M. Watanabe, A. C. Junior, V. R. Uzêda, R. P. d. M. Fortes, T. A. S. Pardo, and S. M. Aluísio, "Facilita: reading assistance for low literacy readers," In Proceedings of the 27th ACM International Conference on Design of Communication, 2009.

[6] D. J. Belder, and M. Moens, "Text simplification for children," In Proceedings of the SIGIR Workshop on Accessible Search Systems, pp. 19–26, 2010.

[7] A. Siddharthan, "Preserving discourse structure when simplifying text," In Proceedings of European Workshop on Natural Language Generation (ENLG), 2002.

[8] S. Alias, S. K. Mohammad, G. K. Hoon, and T. T. Ping, "A Malay text corpus analysis for sentence compression using pattern-growth method," Jurnal Teknologi, 78(8), 2016.

[9] S. Alias, S. K. Mohammad, G. K. Hoon, and M. S. Sainin, "Understanding Human Sentence Compression Pattern for Malay Text Summarizer," In 2018 Fourth International Conference on Information Retrieval and Knowledge Management (CAMP) (pp. 1-6). IEEE, 2018.

[10] D. Gerz, I. Vulić, E. Ponti, J. Naradowsky, R. Reichart, and A. Korhonen, "Language modeling for morphologically rich languages: Character-aware modeling for word-level prediction," Transactions of the Association of Computational Linguistics, 6, pp. 451-465, 2018.

[11] S. A. M. Noah, N. M. Ali, and M. S. Hasan, "*Penjanaan Ringkasan Isi Utama Berita Bahasa Melayu berdasarkan Ciri Kata* (Generation of News Headline for Malay Language based on Term Features)," GEMA Online® Journal of Language Studies, 18(4), 2018.

[12] D. Jurafsky and J. H. Martin, Speech and language processing (Vol. 3). London: Pearson, 2014.

[13] F. Ali, D. Kwak, P. Khan, S. H. A. Ei-Sappagh, S. R. Islam, D. Park and K. S. Kwak, "Merged ontology and SVM-based information extraction and recommendation system for social robots," IEEE Access, 5, pp. 12364-12379, 2017.

[14] M. N. Ayyaz, I. Javed, and W. Mahmood, "Handwritten character recognition using multiclass svm classification with hybrid feature extraction," Pakistan Journal of Engineering and Applied Sciences, 2016.

[15] P. Ficamos, Y. Liu, and W. Chen, "A naive bayes and maximum entropy approach to sentiment analysis: Capturing domain-specific data in weibo". In 2017 IEEE International Conference on Big Data and Smart Computing (BigComp) (pp. 336-339). IEEE, 2017.

[16] Z. Yan, D. Tang, N. Duan, S. Liu, W. Wang, D. Jiang, ... and Z. Li, "Assertion-based QA with Question-Aware Open Information Extraction," In Thirty-Second AAAI Conference on Artificial Intelligence, 2018.

[17] D. Thai, S. H. Ramesh, S. Murty, L. Vilnis, and A. McCallum, "Embedded-State Latent Conditional Random Fields for Sequence Labeling," arXiv preprint arXiv:1809.10835, 2018.

[18] P. Fornacciari, M. Mordonini, A. Poggi, L. Sani, and M. Tomaiuolo, "A holistic system for troll detection on Twitter." *Computers in Human Behavior*, 89, pp. 258-268, 2018.

[19] M. Shardlow, "Lexical simplification: optimising the pipeline," The University of Manchester (United Kingdom), 2015.

[20] G. Paetzold and L. Specia, "Lexical simplification with neural ranking," In Proceedings of the 15th Conference of the European Chapter of the Association for Computational Linguistics: Volume 2, Short Papers, pp. 34-40, 2017.

[21] S. Stajner and H. Saggion, "Data-Driven Text Simplification". In Proceedings of the 27th International Conference on Computational Linguistics: Tutorial Abstracts, 19–23. Association for Computational Linguistics, 2018.

[22] A. Siddharthan, A. Nenkova, and K. McKeown, "Information status distinctions and referring expressions: An empirical study of references to people in news summaries," Computational Linguistics, 37(4), pp. 811–842, 2011.

[23] H. V. Jagadish, T. N. Raymond, C. O. Beng, and K. H. Anthony, "ItCompress: An Iterative Semantic Compression Algorithm," In Proceedings. 20th International Conference on Data Engineering, 2004.

[24] A. Omri and A. Rapport, "Universal Conceptual Cognitive Annotation (UCCA)," In Proceedings of the 51st Annual Meeting of the Association for Computational Linguistics,1, pp. 228–238, 2013.

[25] S. Narayan, and C. Gardent, "Unsupervised Sentence Simplification Using Deep Semantics". In Proceedings of the 9th International Natural Language Generation conference, pp. 111–120, 2016.

[26] A. Omri and A. Rapport, "The State of the Art in Semantic Representation," 2017.

[27] E. Sulem, O. Abend, and A. Rappoport, "Simple and effective text simplification using semantic and neural methods," In Proceedings of the 56th Annual Meeting of the Association for Computational Linguistics 1, pp. 162–173, 2018.

[28] D. Ceglarek, "Semantic compression for text document processing," Trans. Computational Collective Intelligence, 2014.

[29] B. Chen, S. Le, H. Xianpei, and A. Bo, "Sentence rewriting for semantic parsing," In Proceedings of the 54th Annual Meeting of the Association for Computational Linguistics, 1, pp. 766–777. 2019.

[30] S. Narayan and C. Gardent, "Hybrid simplification using Deep Semantics and Machine Translation," In Proceedings of the 52nd Annual Meeting of the Association for Computational Linguistics, pp. 435–445, 2015.

[31] C. Niklaus, B. Bermeitinger, S. Handschuh, and A. Freitas, "A sentence simplification system for improving relation extraction," In Proc. of COLING'16, 2016.

[32] G. Smolenska, *Complex Word Identification for Swedish*. MS thesis, Dept. of Linguistics and Philology, Uppsala University, Sweden, 2018.

[33] J. A. Bakar, Development of a Malay Part-of-Speech Tagging for Jawi Characters based on Maximum Entropy Model with Contextual Information (in Malay language). Ph.D. Thesis, Universiti Kebangsaan Malaysia, 2016.

[34] H. Mohamed, N. Omar, and M. J. Ab Aziz, "Statistical malay part-of-speech (POS) tagger using Hidden Markov approach," In 2011 International Conference on Semantic Technology and Information Retrieval, pp. 231-236, IEEE, 2011.

[35] N. Saphra and A. Lopez, "Language Models Learn POS First," In Proceedings of the 2018 EMNLP Workshop BlackboxNLP: Analyzing and Interpreting Neural Networks for NLP, pp. 328-330, 2018.

[36] S. Ab Rahman, N. Omar, and M. J. Ab Aziz, "The effectiveness of using the dependency relations approach in recognizing the head modifier for malay compound nouns," In 2014 International Conference on Computer and Information Sciences (ICCOINS), pp. 1-5, IEEE, 2014.

[37] S. M. Yimam, H. M. Alonsso, S. Stajner, M. Riedl, and C. Biemann, "Learning Paraphrasing for Multiword Expressions," In *Proceedings of the 12th Workshop on Multiword Expressions,* Association for Computational Linguistics, pp. 1–10, 2016.

[38] A. Davies, Native speakers and native users: Loss and gain. *Cambridge University Press,* 2013.

[39] T. Jussinojo, Life-Cycle of Internet Trolls. Master's Thesis, University of Jyväskylä, 2018.

[40] S. N. M. A. Rashid and N. A. Yaakob, "*Jenis bahasa sindiran dalam ujaran Vlog* (The type of sarcastic language in Vlog speech)," International Journal of Language Education and Applied Linguistics, 2017.

[41] M. F. Salim, *Text simplification using Syntactic Simplification Approach* [Unpublished manuscript]. School of Computing, Universiti Utara Malaysia, 2022.

[42] S. M. Yimam, S. Stajner, M. Riedl, and C. Biemann, "CWIG3G2 – ComplexWord Identification Task across Three Text Genres and Two User Groups," In Proceedings of the Eighth International Joint Conference on Natural Language Processing, 2, Taipei, Taiwan, Asian Federation of Natural Language Processing, pp. 401– 407, 2017.

# A Reduced Feature-Set OCR System to Recognize Handwritten Tamil Characters using SURF Local Descriptor

Ashlin Deepa R N[1], S.Sankara Narayanan[2], Adithya Padthe[3], Manjula Ramannavar[4]

Department of Computer Science and Engineering,
Gokaraju Rangaraju Institute of Engineering and Technology, Hyderabad, India[1]
Department of Computing Technologies, SRM Institute of Science and Technology, Kattankulathur[2]
University of Cumberlands, USA[3]
Department of Computer Science and Engineering, KLS Gogte Institute of Technology, Affiliated to Visvesvaraya Technological
University Udyambag, Belagavi, Karnataka[4]

*Abstract*—**High dimensionality in variable-length feature sets of real datasets negatively impacts the classification accuracy of traditional classifiers. Convolutional Neural Networks (CNNs) with convolution filters have been widely used for handling the classification of high-dimensional image datasets. However, these models require massive amounts of high-dimensional training data, posing a challenge for many image-processing applications. In contrast, traditional feature detectors and descriptors, with a minor trade-off in precision, have shown success in various computer vision tasks. This paper introduces the Nearest Angles (NA) classifier tailored for a handwritten character recognition system, employing Speeded-Up Robust Features (SURF) as local descriptors. These descriptors make local decisions, while global decisions on the test image are accomplished through a ranking-based classification approach. Image similarity scores generated from the SURF descriptors are ranked to make local decisions, and these ranks are then used by the NA classifier to produce a global class similarity score. The proposed method achieves recognition rates of 96.4% for Tamil, 96.5% for Devanagari, and 97 % for Telugu handwritten character datasets. Although the proposed approach shows slightly lower accuracy compared to CNN-based models, it significantly reduces the computational complexity and the number of parameters required for the classification tasks. As a result, the proposed method offers a computationally efficient alternative to deep learning models, lowering the computational time multiple times without a substantial loss in accuracy.**

*Keywords—Image processing; feature extraction; Convolutional Neural Networks; SURF; handwritten character recognition; optical character recognition system*

## I. INTRODUCTION

Human-machine interaction is increasingly becoming a cornerstone in various applications that span daily life. Among these applications, Optical Character Recognition (OCR) stands out as a key technology that facilitates the conversion of different types of handwritten or printed characters into machine-encoded text, generally in ASCII or UNICODE formats [1]. This technology finds various applications ranging from document digitization to automated data entry. For economically deprived and rural populations in India, an effective handwritten OCR system in native languages can significantly enhance computer usability and information accessibility, thereby bridging the digital divide [2].

Despite advances in OCR technologies, there are still significant challenges that affect the performance of OCR systems for handwritten texts, especially in Indian languages [3] [4]. These challenges include inconsistencies in writing styles, structural similarity between symbols, and noise in input images [5] [6]. In addition, existing solutions such as Convolutional Neural Networks (CNNs) require massive computational resources and extensive high-dimensional data for training, making them less feasible for resource-constrained environments [7] [8] [9]. Moreover, CNN-based solutions might not be effective in handling variable-length feature sets or high-dimensional data without a large corpus of training samples [10] [11] [12]. Speeded-Up Robust Features (SURF) descriptors are a type of feature descriptor that is commonly used in image processing and OCR [13]. However, they have been shown to be less effective for handwritten text, due to the structural variations and noise that can be present in input images. This can lead to inaccurate feature extraction, which can in turn degrade the performance of the OCR system. Singular value decomposition (SVD) is a technique for reducing the dimensionality of high-dimensional data [14]. It is often used in OCR to improve the performance of feature extraction and classification. However, SVD can be computationally expensive, especially for large-scale applications. This can limit the practical applicability of SVD-based OCR systems.

The primary aim of this research is to tackle the challenges associated with the OCR system for handwritten characters in Indian languages by introducing a computationally efficient and yet accurate classifier. Specifically, this study introduces the Nearest Angles (NA) classifier, designed for a handwritten character recognition system. This classifier operates in tandem with SURF as local descriptors. Unlike CNN-based solutions that need to process high-dimensional data as a whole, the NA classifier breaks down the problem into more manageable parts by making local decisions based on the SURF descriptors.

The SURF descriptors are employed to extract features from the handwritten characters. These descriptors capture local features from images, making them less sensitive to writing inconsistencies and noise. Upon feature extraction, the NA classifier comes into play. The classifier uses a ranking-based classification approach that relies on generating image similarity scores from the SURF descriptors. These scores are then ranked for making local decisions. Based on the ranks, the NA classifier generates a global class similarity score that is used for classifying the test data. The overall method leverages local decision-making to reduce the computational burden and achieves classification accuracy rates of 91.0% for Tamil, 94.7% for Devanagari, and 88% for Telugu handwritten character datasets.

*1) Introduction of nearest angles (NA) classifier*: Developed a new classifier specifically tailored for handwritten character recognition systems, which is computationally more efficient than existing deep learning approaches.

*2) Integration with SURF descriptors*: Demonstrated the efficacy of using SURF as local descriptors in combination with the NA classifier, thus offering a balanced trade-off between computational complexity and classification accuracy.

*3) Ranking-based classification approach*: Introduced a unique ranking-based classification method that generates a global class similarity score based on local decisions, simplifying the classification task without a significant loss in accuracy.

*4) Multilingual support*: Validated the approach across multiple Indian languages including Tamil, Devanagari and Telugu, thus showing its versatility and wide applicability.

*5) Resource efficiency*: Demonstrated that the proposed method significantly reduces the computational time and the number of parameters required for classification tasks, making it suitable for resource-constrained environments.

These contributions collectively highlight the novel aspects of this research, showcasing its importance in the fields of OCR and machine learning, especially in the context of Indian languages and resource-constrained environments.

## II. LITERATURE REVIEW

First, the Indian scripts lack a sound HCR system due to their complex nature. Most image processing applications use deep-learning-based models such as CNN and produce promising results [15]. The algorithms for deep learning have substantially improved, functioning exceptionally in a variety of fields with robust safety features [16], [17], [18]. In the context of supervised learning, CNN needs a lot of data to enhance its ability to learn and generalization. Else, it leads to overfitting and data shortage [19]. CNNs have emerged as the method of choice for computer vision tasks involving classification, clustering, and other image-processing applications. But here, general-purpose object recognition tasks frequently appear to produce low-level characteristics [20]. Many studies are made to evaluate the complexity of CNN models. In a recent study on the time complexity of

eight deep-learning models, the number of convolution layers, filters, pooling layers, and fully connected layers are varied and tested. The authors found that these layers directly affect the system's performance [21]. Speeded-Up Robust Features (SURF) [22] provides a patented local feature detector and descriptor. Handwritten character images vary in shape and size, and each image has a distinct number of SURF descriptions derived from it. That means the feature vector of each character image is variable in length. Since most classifiers are intended to use fixed-length strings, a variable-length vector of features poses a challenge. On the part of handling variable length feature vectors, Singular Value Decomposition (SVD) is used along with SVM [23]. An approach in which feature vectors are the chromosomes of GA where two variable length strings are handled by padding one of them with {1,0,#} and the classifier was defined as VGA-classifier [24]. In the previous approach called 'Modified-GA', feature vectors are variable length in nature and are handled by appending '00' at the end [25]. However, these methods amplify the complexity in terms of storing and processing the information.

To incorporate a deep-learning-based classification approach, Surf-CNN was proposed, in which local features are extracted by SURF, and CNN is used for classification [20]. In a study, the presence and location of crack information in concrete structures are determined using SURF features and CNN [26]. When SIF and SURF descriptions are incorporated, the deep-learning-based methods can outperform traditional VGG16 and MobileNetV2 [27]. The number of parameters used in CNN is huge which leads to complexity in the classification systems which can be avoided if the accuracy can be slightly compromised.

Simple algorithms such as Nearest Neighbor (NN) can address a variety of classification issues [28]. The fundamental goal of NN is computing the distances globally between the competing patterns, and then ranking them to select the NN that characterizes a test pattern's class most accurately. Computing the distances between patterns is done by distance metrics and which can be degraded by noise and natural variability. If the feature vector is very large and if there exists a falsely assumed correlation, it may produce an irrelevant distance correlation. A rise in feature dimension causes a classification process to converge more slowly and erroneously [29]. The NN classifier is modified to address the aforementioned challenges and the classification of the test data is made by choosing the Nearest Features (NF) of the train data [30]. However, this method only works with feature vectors of the specified length. Due to these reasons, developing a classifier that deals with variable-length high-dimensional input is still an unresolved challenge in technology. In this paper, a novel Nearest Angle (NA) classification algorithm based on SURF descriptors and angles between the matching Interest Points is proposed. This method produces local-level similarity scores and rankings and finally generates the overall result of the classifier for a global decision on the test pattern.

SURF is a scale and rotation invariant feature detector and a simple and accurate descriptor with good repeatability, robustness, and distinctiveness [31]. The feature extraction

process of SURF is composed of two steps. First, detect interest points (IP) from the meaningful structures of an image, which means finding the same physical structures under diverse viewing conditions. This method gives local features with the required level of invariance due to its focus on scale and rotation invariant feature detector and descriptor. These IPs which are characterized by feature descriptors are matched between different images. The search of correspondence requires the comparison of IPs in images where they are seen at different scales. The descriptor space of two images is considered at a time and the descriptor distances of all possible combinations of IP pairs between the images are calculated. These IP pairs along with a classification approach with a small number of parameters play a major role in the proposed method for the classification of the handwritten character recognition system that is considered for this study.

## III. PROPOSED METHODOLOGY

In this section, we discuss the algorithms and methods involved in the proposed Nearest Angles (NA) classifier for handwritten character recognition. First, we resize all images to a uniform size of 256x256 pixels. Then, we extract SURF descriptors from each image. SURF descriptors are a type of feature that is robust to noise and changes in illumination. Next, we find the nearest interest point in each training image for each interest point in the test image using a minimum distance criterion. The crux of our method is to calculate the angle between each pair of corresponding interest points. We then use these angles to classify the test image by assigning it to the class of the training image with the nearest angle. To improve the accuracy of our classification, we use a "top-rank" technique that considers the highest-scoring training images to be more representative of their class. Finally, we use a global decision-making phase to assign the test image to one of the established classes. This phase involves systematic calculations and normalizations. The overall process flow of this proposed method is represented in Fig. 1.

### A. Nearest Angles (NA) from SURF Feature Detector and Descriptor

A simple variant of the Nearest Neighbor classifier called the Nearest Angles (NA) classifier is proposed that is robust during recognition of the text recognition system, with the variable-length feature vector. The utilization of deep learning techniques and the complexities of computation brought on by larger dimensions and parameters can be minimized if an easy-to-use method is created to handle the IPs produced by SURF descriptors [32]. The proposed approach extends the classification decision at the local level and at the global level. This increases the chance of overcoming the misclassification of local classifiers. The following sections explain how to determine different NAs for local-level decisions and finally, the classification of the test data using the NA classifier is given in detail. As the number of SURF descriptors is large and varies in number from image to image, only a few of them are shown in Table I-II, to illustrate the proposed method.

### B. Determination of Matching Interest Point Pairs from SURF Descriptors

The proposed method extracts Nearest Angles (NAs) from the SURF matching points between two images in the spatial coordinate domain. The previous approach, the NIP classifier, illustrates a sample training set and test image with few *IPs[32]*. The training data contains 3, 3 and two images from the classes C1, C2, and C3 respectively. The training data: $G \in \{C_{11}, C_{21}, C_{31}, C_{12}, C_{22}, C_{32}, C_{13}, C_{23}\}$. Let $C_{jc}$ is the $j^{th}$ image of class *c*. For each image, a different number of IPs are produced. Let $In_{ijc}$ be the $i^{th}$ IP of $j^{th}$ object of the class *c*. Each IP is described by a local descriptor vector of fixed size. Two images are compared by computing the IP-to-IP distance between M IPs of each image $C_{jc}$ *with M IPs and the test image Z.*

Evaluating the Distance between IPs

Considering the training data, where the IPs of each image with a class label c is $\{T = \{In_{pj_c}, \forall p, j, c \in [1, X], X \in$ Integer $\}$ and IPs of the image n with a label $\bar{c}$ is $\{H = \{In_{qn_{\bar{c}}}, \forall m, n, \bar{c} \in [1, X], X \in$ Integer $\}$ where $c \neq \bar{c}$ and $c, \bar{c} \in$ Class Label and p and q varies from 1 to number of IPs of images j and n respectively. Let us calculate the distance between two images j and n by calculating the distance between their IPs. $In_{ij_c}$ is $i^{th}$ IP of image j from class c and $In_{mn_{\bar{c}}}$ is $m^{th}$ IP of image n from class $\bar{c}$. The distances among IPs $In_{ij_c}$ and $In_{mn_{\bar{c}}}$ are computed using simple trigonometry [32]. The distance between two IPs $In_{ij_c}$ and $In_{mn_{\bar{c}}}$ is calculated using Eq. (1).

$$d = |In_{ij_c} - In_{mn_{\bar{c}}}|/\sqrt{2} \quad (1)$$

The minimum distance is determined after repeating this method for every IPs of n in H and using Eq. (2).

$$di = min\{|In_{ij_c} - In_{qn_{\bar{c}}}|/\sqrt{2}\}, \quad (2)$$

where q ranges from 1 to the total number of IPs in the image *n*. The $m^{th}$ IP of n $In_{mn_{\bar{c}}}$, with minimum distance *di* is taken to form a matching pair $(In_{ij_c}, In_{mn_{\bar{c}}})$. The meaning is $i^{th}$ IP of image *j* from class produced minimum distance with $m^{th}$ IP of image *n* from class $\bar{c}$. Repeat the above technique for all the IPs in set *G* to determine the matching pairs of *IPs* of image *j* (see Fig. 2).

Fig. 3(a) to Fig. 3(b) shows the images and IPs forming correct matching pairs (each straight line represents a line connecting the IPs of each matching pair at comparing images). The angle between the two points in the matching pair is computed by the principle of trigonometry as shown in Fig. 3(c) to Fig. 3(d). For every matching IP pair, four angles can be generated. But any one of the angles is sufficient to decide NAs. Fig. 3 shows the two Tamil character images 'Ah' and the points A and B are the IPs in a matching pair after applying the distance Eq. (2) over SURF descriptors in both images. Let PQ and RS be the lines drawn parallel to these points. The ∠ABR and ∠BAQ are alternate interior angles and are equal. As when parallel lines get crossed by another line, alternate interior angles are equal and are calculated as given in Definition 1. Similarly, ∠PAB and ∠ABS are also alternate interior angles.
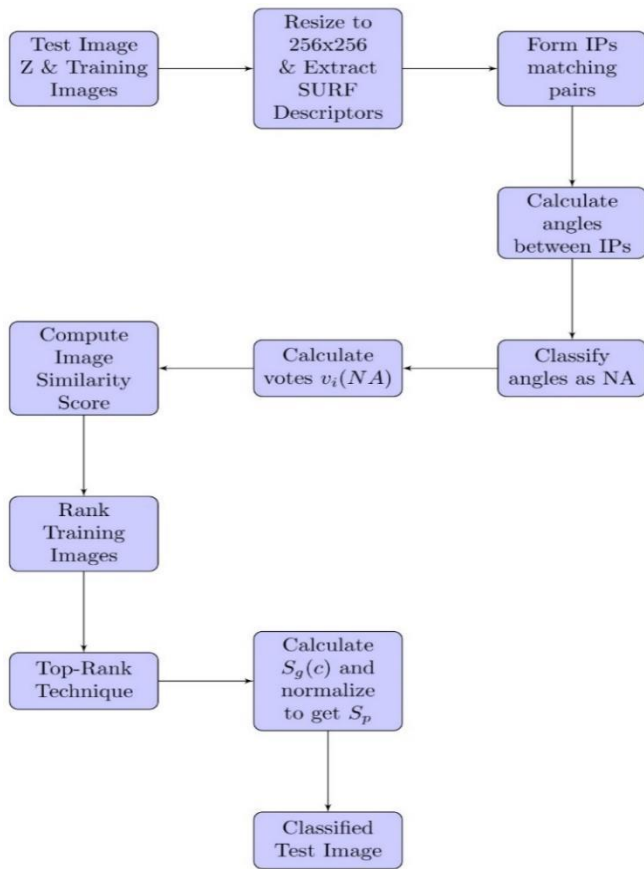
Fig. 1. Overall process flow of the proposed nearest angles (NA) classifier for handwritten character recognition.

Two values are obtained from each alternate interior angle, so four angles are obtained from each matching pair of IPs. Only one angle value is used for processing for each matching IP pair as the proposed method works for all four angles at the same time. Initially, the bounding box of both the test and training images are calculated and resized to 256 x 256, then SURF features are extracted and matching pairs are generated using the IPs of both the images used for comparison. A line is drawn to connect both the IPs of the matching pair. Parallel lines are drawn to detect the angles between the line drawn and the corresponding axis (see Definition 1).

**DEFINITION 1:** *When a line crosses parallel lines, alternate interior angles $An = (\frac{y2-y1}{x2-x1}) * \frac{180}{\pi}$ are equal where (x1, y1) and (x2, y2) are the coordinates of the line crossing the parallel lines.*

### C. Determination of NAs

For each matching pair between the test and training image, two pairs of angles are produced as alternate interior angles as in Fig. 2(d) ∠PAB and ∠ABS are alternate interior angles and so ∠PAB =∠ABS. Similarly, ∠ABR and ∠BAQ are

alternate interior angles and so ∠ABR = ∠BAQ). And there are two distinct values out of four angles as alternate interior angles are equal. But, any one of the values out of two can be used for processing. Table I shows the angle generated between the IPs of test image Z and each of the training images (only one angle of particular IP matching pair is given). There are seven images in the training set and each image is with different number of IPs. The test image Z produces IPs matching pair with *IPs* of the training image, and the angles between IPs from the matching pair are calculated using Definition 1 and are shown in Table I. After determining the angle between IPs in the matching pair, the next step is to determine the NAs of each of the training images.

**DEFINITION 2:** *An angle $a_n$ between the IPs from the test image and training image j in the matching pair is classified as one of the NAs of training image j if and only if $|\theta_{lan}| \leq a_n \geq |\theta_{uan}|$ where $\theta_{lan}$ and $\theta_{uan}$ are the upper and lower bounds of NA detection threshold.*

After calculating the angle $a_n$ of IPs from each matching pair of the training image j, a comparison is made with the $\theta_{lan}$ and $\theta_{uan}$, which are lower and upper bound NA detection threshold values respectively. When compared with the threshold values $\theta_{lan}$ and $\theta_{uan}$, based on Definition 2, these angles give the measure of closeness of *IP* of test image Z, with the training image j and which is used to make a local decision using NAs. An angle $a_n$ is said to be NA of training image j, if it is greater than $\theta_{lan}$ and less than $\theta_{uan}$. The process of determining the NAs is given by voting as shown in Eq. (3).

$$vi(NA) = \begin{cases} 1, & if\ \theta_{lan} \leq a_n \leq \theta_{uan} \\ 0, & otherwise \end{cases} \quad (3)$$

If vi(NA)=1, the angle $a_n$ is considered as NA between the training and test image.

### D. Local Decision using NAs Classifier

The angle $a_n$ from a training image is said to be the Nearest Angle (NA), if and only if $|\theta_{lan}| \leq |a_n| \leq |\theta_{uan}|$ where $\theta_{lan}$ and $\theta_{uan}$ are lower and upper bounds of NAs threshold values which are assumed to be 80 and 100 respectively. Each NA of the training image carries a vote *vi(NA)*of 1. For each of the training images, the image similarity score is calculated by summing up its *votes* on *NAs which are* shown in Table I.

The training image $C_{11}$ produces the matching pairs *(In$_{111}$, InZ_1), (In$_{211}$, InZ_3), (In$_{311}$, InZ_5)* and *(In$_{411}$, InZ_4)* with test image Z and the angles $a_n$ calculated are 80,110,102 and 96 respectively. The votes are generated by comparing the angles with the threshold values of NA $\theta_{lan}$ and $\theta_{uan}$. Using (4) the Image similarity score for training image $C_{11}$ is 2 as angles 80 and 96 are greater than the threshold $\theta_{lan}$ (i.e.,80) and are less than $\theta_{uan}$ (i.e.,100) and 110 and 102 are greater than $\theta_{uan}$ (i.e.,100). These image similarity scores at the local decision phase are maintained to determine the class of the test image at the global level.

TABLE I. THE PROPOSED NA VOTE AND IMAGE SIMILARITY SCORE COMPUTATION TO DETERMINE THE CLASS OF Z FROM THE TAMIL HANDWRITTEN CHARACTER DATABASE

| Class-label | Object label | Matching-pair | Angle | Matching-pair | Angle | Matching-pair | Angle | Matching-pair | Angle | Matching-pair | Angle | Image similarity score based on NAs | Normalized image similarity score |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | IPs of the test image Z are $InZ_1, InZ_2, InZ_3, InZ_4$ and $InZ_5$ | | | | | | | | | | | |
| C1 | $C_{11}$ | $(In111, InZ_1)$ | 80 | $(In211, InZ_3)$ | 110 | $(In311, InZ_5)$ | 1022 | $(In411, InZ_4)$ | 96 | | | 2 | 2/4=.5 |
| | vote | 1 | | 0 | | 0 | | 1 | | | | | |
| | $C_{21}$ | $(In121, InZ_2)$ | 96 | $(In221, InZ_1)$ | 100 | $(In321, InZ_3)$ | 89 | $(In421, InZ_4)$ | 86 | $(In521, InZ_5)$ | 93 | 5 | 5/5=1 |
| | vote | 1 | | 1 | | 1 | | 1 | | 1 | | | |
| | $C_{31}$ | $(In131, InZ_1)$ | 120 | $(In231, InZ_2)$ | 89 | $(In331, InZ_3)$ | 93 | $(In431, InZ_5)$ | 85 | | | 3 | ¾=.75 |
| | vote | 0 | | 1 | | 1 | | 1 | | | | | |
| C2 | $C_{12}$ | $(In112, InZ_1)$ | 97 | $(In212, InZ_4)$ | 110 | $(In312, InZ_3)$ | 131 | $(In412, InZ_5)$ | 142 | | | 1 | ¼=.25 |
| | vote | 1 | | 0 | | 0 | | 0 | | | | | |
| | $C_{22}$ | $(In122, InZ_1)$ | 80 | $(In222, InZ_3)$ | 95 | $(In322, InZ_5)$ | 118 | $(In422, InZ_2)$ | 94 | $(In522, InZ_4)$ | 88 | 4 | 4/5=.8 |
| | vote | 1 | | 1 | | 0 | | 1 | | 1 | | | |
| | $C_{32}$ | $(In132, InZ_2)$ | 127 | $(In232, InZ_1)$ | 122 | $(In332, InZ_4)$ | 94 | $(In432, InZ_3)$ | 107 | $(In532, InZ_5)$ | 140 | 1 | 1/5=.2 |
| | vote | 0 | | 0 | | 1 | | 0 | | 0 | | | |
| C3 | $C_{13}$ | $(In113, InZ_2)$ | 130 | $(In213, InZ_3)$ | 136 | $(In313, InZ_1)$ | 129 | | | | | 0 | 0 |
| | votes | 0 | | 0 | | 0 | | | | | | | |
| | $C_{23}$ | $(In123, InZ_1)$ | 98 | $(In223, InZ_3)$ | 117 | $(In323, InZ_2)$ | 82 | $(In423, InZ_5)$ | 128 | $(In523, InZ_4)$ | 132 | 2 | 2/5=.4 |
| | votes | 1 | | 0 | | 1 | | 0 | | 0 | | | |

TABLE II. DETERMINATION OF THE CLASS OF Z BASED ON GLOBAL DECISION

| Collective class similarity scores, $S_g(c)$ | | | | Class probability score for each rank $S_p$ | | | |
|---|---|---|---|---|---|---|---|
| | Rank | | | | Rank | | |
| Class, c | 1 | 2 | 3 | 1 | 2 | 3 | |
| C1 | 1 | 1.75 | 2.25 | **1/1=1** | 1.75/1.75=1 | 2.25/2.25=1 | |
| C2 | .8 | 1.05 | 1.25 | .8/1=.8 | 1.05/1.75=.6 | 1.25/2.25=.55 | |
| C3 | .4 | .4 | - | .4/1=.4 | .4/1.75=.228 | | |

| Matching pair (IP of image C11, IP of image Z) | |
|---|---|
| $In_{111}$ | $In_{Z1}$ |
| $In_{211}$ | $In_{Z-2}$ |
| $In_{311}$ | $In_{Z5}$ |
| $In_{411}$ | $In_{Z4}$ |

(a)      (b)
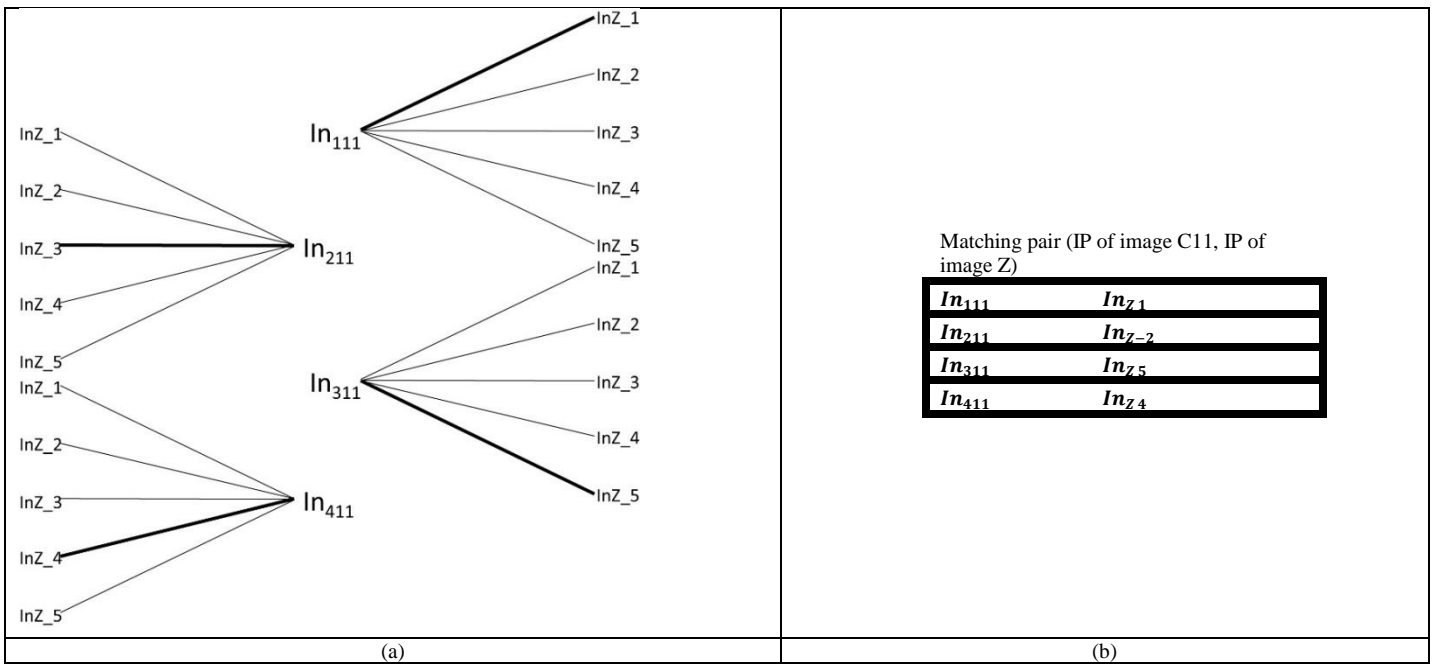
Fig. 2.  (a). Matching pair formation between the IPs of C11 and Z. Solid line indicates the best match with minimum distance between IPs.  (b) Best matches between IPs of C11 and Z.



(a)      (b)      (c)



(d)
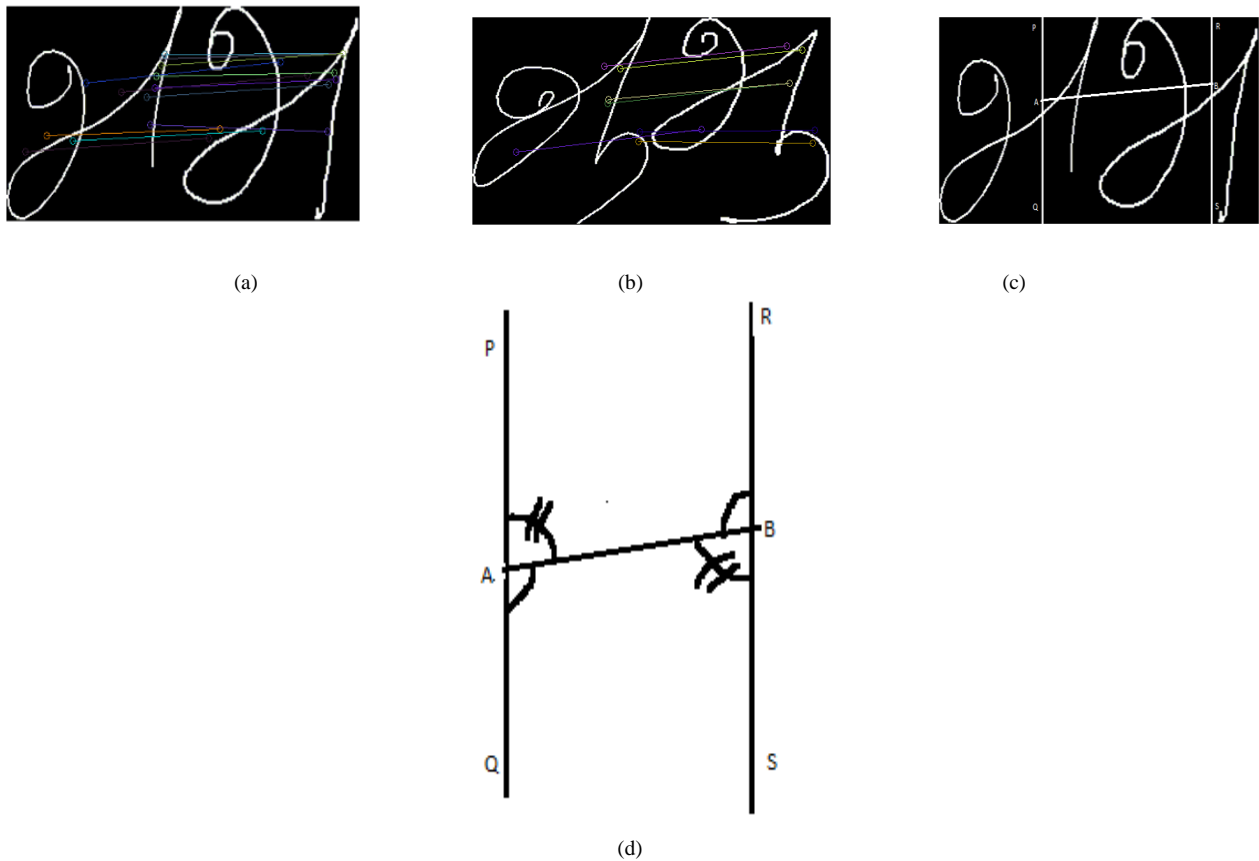
Fig. 3.  (a) and (b)Two intra-class Tamil Character images, 'Ah' and 'AAh', respectively, showing Matching pair with minimum distance. (c) Two Tamil Character images 'Ah' with matching IPs at points A and B. (d) The line connects the two points A and B and four angles can be produced between these two points, ∠PAB, ∠BAQ, ∠ABR and ∠ABS. (b)∠PAB and ∠ABS are alternate interior angles and so ∠PAB =∠ABS. Similarly, ∠ABR and ∠BAQ are alternate interior angles and so ∠ABR = ∠BAQ.

The Image similarity score gives the local decision on the closeness of IPs of the test data with training data.

### E. Classification using Global Decision on Similarity Scores

The global decision on the recognition of test images is done by considering the 'top-rank' technique. Accordingly, the image in the training set, at each class, with the highest value in the 'image similarity score' is considered for further processing. In this method, the training image with the highest 'Image similarity score' in each class is considered to represent the whole class. That means, the training image in each class with a higher similarity value is calculated and is termed as collective class similarity score $S_g(c)$ at 'Rank 1' and is given in Table II. Class probability scores $S_p$ is calculated by normalizing the collective class similarity score $S_g(c)$ by dividing it by the maximum similarity score across the classes. The highest value of Sp across the classes is considered as the class of the test image Z, c*, which can be denoted as Eq. (4).

$$c^* = arg\ max\ S_p(c) \qquad (4)$$

The top-rank approach generally gives many classes as outputs despite the fact that it facilitates decision-making at the global level. Therefore, the image similarity score at lower rankings is taken into account, and an algorithmic sum is performed at each ranking level. The image-level similarity scores at first and second ranks from each class are summed up to calculate the collective class similarity score $S_g(c)$ at Rank 2. This process is repeated for the subsequent lower-ranking levels. The rank-wise normalization *of $S_g(c)$* throughout all the classes yields *class probability scores, $S_p$.* A tie-in-the-top-rank method is solved by adding the $S_p$ values at the lower rankings. It would eliminate the ambiguity in class assignments caused by ties. The rank 1 $S_p$ score of C1 yields the highest value of 1 with no ties (see Table II). The model is evaluated up to three ranking levels since an acceptable recognition is obtained close to rank 3 in the NA classification.

### F. Overall Process Flow of Proposed NA Classifier

The Nearest Angles (NA) Classifier for Text Recognition using SURF Descriptors is a novel algorithm designed to address the challenges of text classification in images. It leverages Speeded-Up Robust Features (SURF) to capture unique descriptors and interest points from a set of pre-labelled training images across multiple categories. This approach enhances the conventional techniques by employing angle-based metrics to establish the nearest matches between the features of a test image and those in the training dataset. The algorithm then computes similarity scores based on these angle metrics to classify the test image into one of the predefined categories. The efficacy of the method lies in its ability to deliver accurate classifications while effectively handling variations in scale, orientation, and illumination. The proposed Nearest Angles (NA) Classifier's process flow is explained in Algorithm 1.

---

**Algorithm 1 NA Classifier for Text Recognition**

1: **Input:**
2: Training image set $G$ with class labels $C1, C2,..., Cn$
3: Test image $Z$
4: Lower bound NA detection threshold $\theta_{lan}$
5: Upper bound NA detection threshold $\theta_{uan}$
6: **Output:**
7: Classified label for the test image $Z$
8: **Steps:**
9: **SURF Feature Extraction**
10: **for** each image $C_{jc}$ in $G$ and test image $Z$ **do**
11: Extract SURFdescriptors and Ips ($IP_{ijc}$ for $C_{jc}$ and $IP_{zn}$ for $Z$)
12: **end for**
13: **Calculate IP-to-IP Distances**
14: **for** each $IP_{ijc}$ and $IP_{zn}$ **do**
15: $d = \frac{|IP_{ijc} - IP_{zn}|}{\sqrt{2}}$
16: **end for**
17: **Find Minimum Distances** 18: **for** each $IP_{ijc}$ **do**
19: $d_i = \min\left(\frac{|IP_{ijc} - IP_{zn}|}{\sqrt{2}}\right)$
20: **end for**
21: **Determine Matching Pairs**
22: **for** each $IP_{ijc}$ **do**
23: Pair $IP_{ijc}$ and $IP_{zn}$ if $d_i$ is minimum
24: **end for**
25: **Calculate Angles for Matching Pairs**
26: **for** each matching pair **do**
27: $Angle(An) = \frac{(y_2 - y_i)}{(x_2 - x_i)} \times \frac{180}{\pi}$
28: **end for**
29: **Determine Nearest Angles (NAs)**
30: **for** each angle $a_n$ **do**
31: **if** $\theta_{lan} \leq a_n \leq \theta_{uan}$ **then**
32: $v_i(NA) = 1$
33: **else**
34: $v_i(NA) = 0$
35: **end if**
36: **end for**
37: **Compute Image Similarity Score**
38: **for** each image $C_{jc}$ **do**
39: Image Similarity Score $= {}^P v_i(NA)$
40: **end for**
41: **Local Decision**
42: Image similarity scores of $m$ top-ranked images are taken to obtain local decisions at 2 NAs.
43: **Global Decision**
44: Calculate class similarity score followed by class probability score to make a more robust global decision

The Nearest Angles (NA) Classifier for Text Recognition using SURF Descriptors is an algorithm designed to classify text images into pre-defined categories. The algorithm starts by extracting Speeded-Up Robust Features (SURF) descriptors and interest points (IPs) from both the training image set, labelled with classes $C1, C2, \dots, Cn$, and a test image $Z$. It calculates the IP-to-IP distances between these features and identifies the minimum distances to form matching pairs of IPs between each training image and the test image. Angles are calculated for these matching pairs, and a "Nearest Angle" (NA) is identified based on lower and upper angle thresholds $\theta_{lan}$ and $\theta_{uan}$. An image similarity score is computed for each training image based on these NAs. The algorithm then classifies the test image $Z$ into the category of the training image with the highest similarity score. Optionally, a global decision can be made by aggregating multiple local decisions.

## IV. RESULTS AND DISCUSSION

### A. System Setup

To evaluate the effectiveness of the NA Classifier, the experiments were conducted on a system equipped with an Intel i7 processor, 16 GB of RAM, and a 1 TB SATA hard drive. The system also featured an NVIDIA GPU. The software environment was MATLAB 2020, specifically utilizing its Deep Learning Toolbox, all running on a Windows 10 operating system.

### B. Experimental Setup

The primary objective of this section is to assess the effectiveness of the proposed NA Classifier for handwritten text recognition, which is designed to reduce the computational burden commonly encountered in existing AI algorithms. The experimental framework is divided into three key components: computational efficiency, accuracy and comparative analysis: Intra-Class vs. Inter-Class Matching. These aspects are rigorously evaluated against a range of state-of-the-art algorithms and models. In the first component, the computational efficiency of the NA Classifier is analyzed to determine whether it effectively reduces processing time without sacrificing performance. In the second component, the method's error rate is examined to assess its reliability in various classification tasks. Finally, the accuracy of the NA Classifier is evaluated, serving as the critical measure of its overall effectiveness. The accuracy of the NA Classifier was evaluated against state-of-the-art methods, including: SurfCNN (A. M. Elmoogy et al. [20]), CNN-based Models (M. Rai and P. Rivas [19]), SURF with SVM (Shagun Katoch et al. [21]), SVD with SVM (Li C et al. [23]), VGG16 and MobileNetV2 (Ardiant Utomo et al. [27]), Nearest Neighbor (Nitin Bhatia, Vandana [28]), Modified-GA (Ashlin Deepa R N, Rajeswara Rao R [32]), Nearest Angle (NA) Algorithm (Alex Pappachen James [30]). The proposed method was also benchmarked against the popular machine learning and deep learning algorithms, including k-nearest neighbors (k-NN), k-means clustering, support vector machines (SVM), decision trees, Naive Bayes, Random Forest, VGG-19, MobileNet, and gradient boosting.

### C. Dataset Details

In this research, we employ three distinct Indic handwriting datasets sourced from HP Lab, focusing on the Tamil, Devanagari, and Telugu scripts. These datasets serve as the foundational testing ground for the evaluation of our proposed method, encompassing a wide array of handwritten textual samples in these languages to validate the robustness and applicability of our approach. Tables III, IV, and V provide details about the Tamil, Telugu, and Devanagari datasets, respectively.

TABLE III. TAMIL DATASET ATTRIBUTE DETAILS

| Criteria | Details |
|---|---|
| Total Classes | 156 |
| Data Format | UNIPEN v1.0, bilevel TIFF images |
| Training Set | 70% of samples from each class, randomly selected |
| Test Set | Remaining 30% of samples from each class |

TABLE IV. TELUGU DATASET ATTRIBUTE DETAILS

| Criteria | Details |
|---|---|
| Total Classes | 166 |
| Data Format | UNIPEN v1.0 |
| Training Set | 70% of samples from each class, randomly selected |
| Test Set | Remaining 30% of samples from each class |

TABLE V. DEVANAGARI DATASET ATTRIBUTE DETAILS

| Criteria | Details |
|---|---|
| Total Classes | 111 |
| Data Format | UNIPEN v1.0, bilevel TIFF images |
| Training Set | 70% of samples from each class, randomly selected |
| Test Set | Remaining 30% of samples from each class |

### D. Computational Efficiency Analysis

Computational efficiency is a critical criterion in the evaluation of deep learning and machine learning algorithms. In recent years, there has been significant research on mitigating the computational overhead associated with deep learning and machine learning techniques. This section evaluates the computational efficiency of the proposed NA classifier on three handwritten datasets: Tamil, Telugu, and Devanagari. For each dataset, 70% of the samples from each class were allocated to the training set, and the remaining 30% constituted the test set. First, we evaluate the training efficiency of the proposed method against state-of-the-art handwritten character recognition methods, deep learning algorithms, and machine learning algorithms.

According to the Fig. 4, the proposed Nearest Angle (NA) classifier demonstrates a notable advantage in computational efficiency across three handwritten datasets: Tamil, Telugu, and Devanagari, with training times of 3.0, 3.2, and 3.4, respectively. These times are significantly lower than those of existing state-of-the-art methods and standard machine learning and deep learning algorithms, such as VGG-19, MobileNet, and SVM, which have training times up to three times higher. This reduced training time implies a lower computational burden, fewer resource requirements, and faster deployment capabilities, thereby making the NA classifier an ideal choice for applications where computational resources and time are critical constraints.
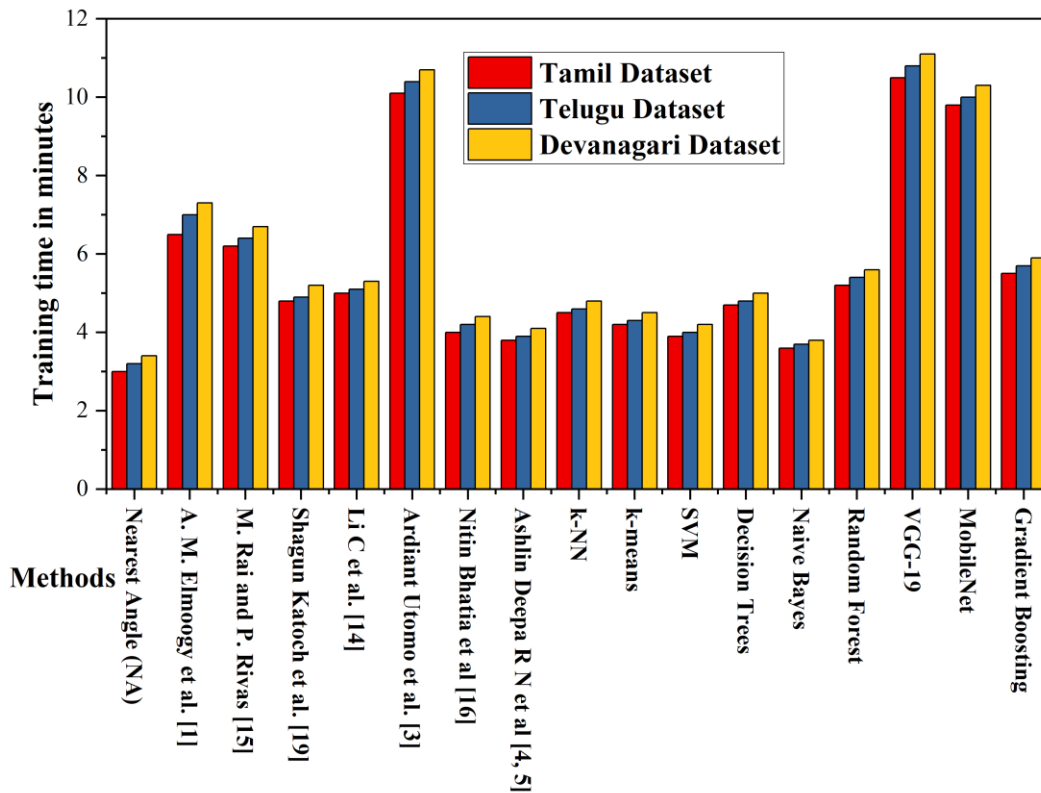
Fig. 4. Comparative analysis of training time across various algorithms and datasets.

To assess the classification time efficiency of the proposed method in a rigorous manner, we adopted a systematic testing approach. Specifically, we randomly selected five samples from each of three different datasets. Each set of five samples was classified using the proposed method and various existing methods for comparison. For each set, we measured the time required to complete the classification and then calculated the average classification time for that set. Finally, we computed an overall average classification time across the three sets to obtain a robust estimate of performance.

The Fig. 5 comparing average classification times reveals that the proposed NA method is the most time-efficient with an average of 0.15 seconds, closely followed by the method proposed by A. M. Elmoogy et al. at 0.18 seconds. Traditional machine learning algorithms like k-NN, k-means, and SVM exhibit moderate speed, ranging from 0.29 to 0.38 seconds, while ensemble methods such as Random Forest and Gradient Boosting are slightly slower within the same category. Notably, deep learning models like VGG-19 and MobileNet are significantly slower, taking around 0.95 and 0.90 seconds respectively, likely due to their complex architectures and higher computational requirements.

Compared to traditional deep learning methods, the proposed NA classifier for text recognition systems significantly reduces classification and training time. This efficiency is largely due to its localized decision-making approach, which focuses on calculating angles between matching Interest Points (IPs) in the spatial coordinate domain. Instead of computing high-dimensional feature vectors and performing complex operations, the NA classifier uses simple calculations to evaluate the closeness of IPs. By considering only angles that fall within predefined upper and lower bound thresholds, the system effectively performs dimensionality reduction. This limits the computational complexity, which is especially beneficial when dealing with large sets of SURF descriptors that can vary in number across images. As a result, this method not only minimizes the chances of misclassification at the local level but also reduces computational overhead, leading to faster classification and training times.

*E. Accuracy Analysis*

Accuracy is a crucial metric for evaluating the performance of the NA Classifier in handwritten text recognition. Specifically, we are interested in the algorithm's effectiveness in identifying individual characters in three datasets: Tamil, Telugu, and Devanagari. In this section, we will outline the metrics used to assess accuracy and present the results in comparison with state-of-the-art models and algorithms. The following metrics are primarily involved in the evaluation of accuracy:
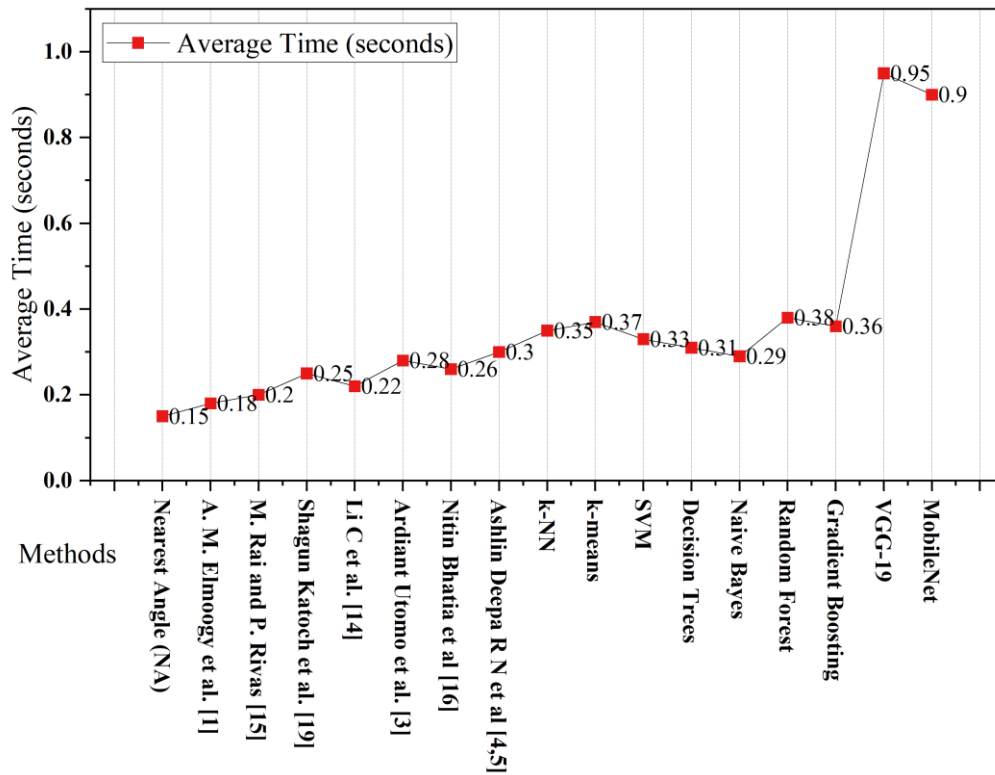
Fig. 5. Average classification time in seconds.

*1) True positives (TP)*: These represent instances where the NA Classifier accurately identifies a character as belonging to a specific class within the dataset.

*2) True negatives (TN)*: These denote situations where the NA Classifier accurately concludes that a given sample does not belong to a targeted class.

*3) False positives (FP)*: These occur when the NA Classifier incorrectly ascribes a sample to a particular class when it should not have.

*4) False negatives (FN)*: These represent the scenarios where the NA Classifier fails to identify a sample as belonging to a specific class when it actually does. Based on these, we calculate the following metrics: Accuracy (ACC), Sensitivity (SEN), Specificity (SPEC), F1-Score, and Matthews Correlation Coefficient (MCC) which are calculated by using following formulas.

$$ACC = \frac{(TP + TN)}{(TP + TN + FP + FN)} \quad (5)$$

$$SEN = \frac{TP}{(TP + FN)} \quad (6)$$

$$SPEC = \frac{TN}{(TN + FP)} \quad (7)$$

$$F1 = 2 * \frac{(precision * recall)}{(precision + recall)} \quad (8)$$

TABLE VI. BENCHMARKING ACCURACY OF NA CLASSIFIER AGAINST STATE-OF-THE-ART METHODS ON TAMIL DATASET

| Methods | ACC | SEN | SPEC | F1-Score |
|---|---|---|---|---|
| Nearest Angle (NA) | 96.4% | 95.8% | 97.3% | 96.0% |
| A. M. Elmoogy et al. [20] | 90.2% | 89.5% | 91.1% | 90.0% |
| M. Rai and P. Rivas [19] | 89.8% | 88.0% | 90.9% | 89.5% |
| Shagun Katoch et al. [21] | 88.5% | 87.6% | 90.0% | 88.0% |
| Li C et al. [23] | 87.0% | 86.1% | 88.5% | 86.5% |
| Ardiant Utomo et al. [27] | 92.3% | 91.0% | 94.0% | 92.0% |
| Nitin Bhatia et al [28] | 85.0% | 83.5% | 86.8% | 84.0% |
| Ashlin Deepa R N et al [32] | 83.7% | 82.9% | 85.2% | 83.0% |
| k-NN | 82.0% | 81.5% | 84.0% | 82.0% |
| k-means | 79.0% | 78.5% | 81.0% | 79.0% |
| SVM | 81.5% | 80.0% | 83.5% | 81.0% |
| Decision Trees | 77.5% | 76.0% | 80.0% | 77.0% |
| Naive Bayes | 76.0% | 74.8% | 78.5% | 75.0% |
| Random Forest | 80.5% | 79.0% | 83.0% | 80.0% |
| Gradient Boosting | 81.0% | 79.5% | 84.0% | 80.5% |
| VGG-19 | 97.2% | 96.8% | 98.0% | 97.0% |
| MobileNet | 97.5% | 97.0% | 98.2% | 97.3% |

TABLE VII.    BENCHMARKING ACCURACY OF NA CLASSIFIER AGAINST STATE-OF-THE-ART METHODS ON TELUGU DATASET

| Methods | ACC | SEN | SPEC | F1-Score |
|---|---|---|---|---|
| Nearest Angle (NA) | 96.5% | 95.8% | 97.2% | 96.1% |
| A. M. Elmoogy et al. [20] | 94.2% | 93.0% | 95.5% | 94.3% |
| M. Rai and P. Rivas [19] | 93.8% | 92.7% | 94.9% | 93.8% |
| Shagun Katoch et al. [21] | 92.5% | 91.2% | 93.8% | 92.5% |
| Li C et al. [23] | 91.8% | 90.1% | 93.5% | 91.8% |
| Ardiant Utomo et al. [27] | 97.2% | 96.9% | 97.5% | 97.2% |
| Nitin Bhatia et al [28] | 89.5% | 88.2% | 90.8% | 89.5% |
| Ashlin Deepa R N et al [32] | 88.3% | 87.0% | 89.6% | 88.3% |
| k-NN | 90.0% | 88.8% | 91.2% | 90.0% |
| k-means | 87.2% | 86.0% | 88.4% | 87.2% |
| SVM | 91.5% | 90.0% | 93.0% | 91.5% |
| Decision Trees | 85.8% | 84.2% | 87.4% | 85.8% |
| Naive Bayes | 84.5% | 82.7% | 86.3% | 84.5% |
| Random Forest | 89.0% | 87.8% | 90.2% | 89.0% |
| Gradient Boosting | 90.5% | 89.2% | 91.8% | 90.5% |
| VGG-19 | 97.5% | 97.0% | 97.2% | 96.5% |
| MobileNet | 97.1% | 96.7% | 97.3% | 97.2% |

TABLE VIII.    BENCHMARKING ACCURACY OF NA CLASSIFIER AGAINST STATE-OF-THE-ART METHODS ON DEVANAGARI DATASET

| Methods | ACC | SEN | SPEC | F1-Score |
|---|---|---|---|---|
| Nearest Angle (NA) | 97.0% | 96.4% | 97.6% | 96.7% |
| A. M. Elmoogy et al. [20] | 95.2% | 94.0% | 96.4% | 95.2% |
| M. Rai and P. Rivas [19] | 94.5% | 93.5% | 95.5% | 94.5% |
| Shagun Katoch et al. [21] | 93.0% | 91.9% | 94.1% | 93.0% |
| Li C et al. [23] | 92.1% | 90.8% | 93.4% | 92.1% |
| Ardiant Utomo et al. [27] | 97.8% | 97.5% | 98.1% | 97.8% |
| Nitin Bhatia et al [28] | 90.5% | 89.2% | 91.8% | 90.5% |
| Ashlin Deepa R N et al [32] | 89.0% | 87.8% | 90.2% | 89.0% |
| k-NN | 91.0% | 89.7% | 92.3% | 91.0% |
| k-means | 87.5% | 86.3% | 88.7% | 87.5% |
| SVM | 92.5% | 91.0% | 94.0% | 92.5% |
| Decision Trees | 86.2% | 84.6% | 87.8% | 86.2% |
| Naive Bayes | 85.0% | 83.3% | 86.7% | 85.0% |
| Random Forest | 89.5% | 88.1% | 90.9% | 89.5% |
| Gradient Boosting | 90.8% | 89.5% | 92.1% | 90.8% |
| VGG-19 | 98.7% | 98.2% | 99.2% | 98.7% |
| MobileNet | 97.3% | 97.0% | 98.6% | 97.3% |

According to the data in Tables VI, VII, and VIII, the NA classifier consistently outperforms traditional machine learning algorithms such as k-NN, k-means, SVM, and Decision Trees across all datasets. In the Tamil dataset, for example, the NA classifier achieved an accuracy of 96.4%, which is notably higher than the closest traditional competitor, Ardiant Utomo et al, at 92.3% (see Table VI). Similar trends are observed in the Telugu and Devanagari datasets as well, where the NA classifier scored 96.5% and 97.0% respectively. In terms of sensitivity and specificity, the NA classifier also performs excellently. It managed to attain 95.8% sensitivity and 97.3% specificity on the Tamil dataset, again superior to

any traditional algorithm (see Table VI). The high sensitivity and specificity scores mean that the NA classifier is proficient at correctly identifying true positives and true negatives, making it a reliable choice for real-world applications. The F1-Score serves as a balanced measure of a model's performance, taking into account both precision and recall. The NA classifier achieves a high F1-Score of 96.0%, 96.1%, and 96.7% on the Tamil, Telugu, and Devanagari datasets, respectively as shown in Table VI, Table VII and Table VIII. This is a significant achievement compared to traditional classifiers. While deep learning methods like VGG-19 and MobileNet slightly outperform the NA classifier in terms of accuracy, they do so at the cost of computational resources. The NA classifier is designed for lightweight applications and is three times more computationally efficient than these deep learning models. In scenarios where computational resources are a concern, this efficiency makes the NA classifier an appealing choice without significantly compromising accuracy.

The NA classifier for handwritten character recognition that is both accurate and efficient. It is not as accurate as deep learning models, but it is much faster. This makes it a good choice for applications where speed is important, such as real-time text recognition on mobile devices. The NA classifier has been shown to work well on multiple datasets, which shows that it is reliable and robust.

### F. Comparative Analysis: Intra-Class vs. Inter-Class Matching

Intra-class and inter-class matching discrimination is a crucial component of image matching in our study. Intra-class matching refers to matching pairs of data points that belong to the same class. Inter-class matching refers to matching pairs of data points that belong to different classes. Fig. 6(a) shows an example of intra-class matching. Both IPs A and B point to the same local physical structures in the two Tamil character images of 'Ah'. However, the NA classifier generates a vote of '0' because the alternate interior angles violate the lower and upper bounds of the NA detection thresholds. This means that the two images are not considered to be NAs. Fig. 6(b) shows an example of inter-class matching. The two IPs point to different local physical structures in the two character class images. The NA classifier also generates a vote of '0' in this case because the alternate interior angles violate the rule of NAs.



(a)
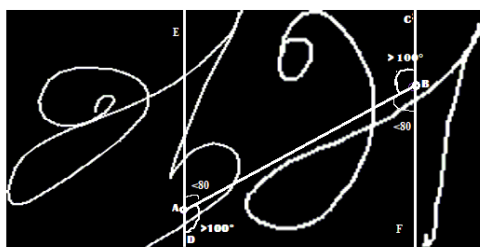
(b)

Fig. 6.   (a) Two intra-class images of Tamil alphabet 'Ah' showing incorrect IPs matching at A and B, so that the angle ∠BAC and ∠ABD have more than 100° and the angle ∠EAB and ∠ABF have less than 80°. (b) Two inter-class images of Tamil alphabet 'AAh' and 'Ah' showing incorrect IPs matching at A and B, so that the angle ∠BAD and ∠ABC have more t100° and the angle ∠EAB and ∠ABF have less than 80°.
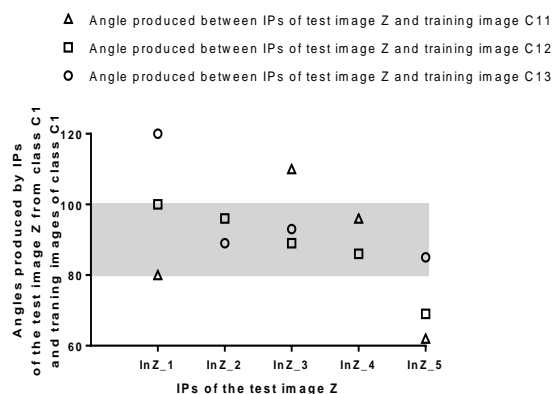


(a)

(b)
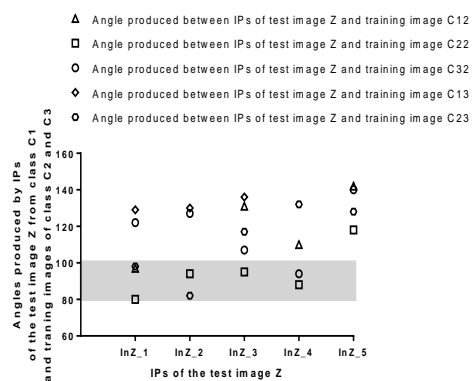


(b)

Fig. 7.   Effect of parameters used in the NA classifier.  (a) Most of the angles produced between IPs of test image Z and training images of class C1 are inside the shaded region which illustrates the allowed boundaries of NA classifier. (b) Most of the angle s produced between IPs of test image Z and training images of class C2 and C3 are outside the shaded region which illustrates the allowed boundaries of NA classifier.

Fig. 7(a) shows the reliability of the threshold values $\theta uan=100$ and $\theta lan=80$ for intra-class matching. Most of the IPs between the test image Z of class C1 and the intra-class

training images C11, C21, and C13 produce angles within the upper and lower bounds. This means that the test image Z is correctly classified as not being an NA. Fig. 7(b) shows the angles formed between inter-class training images and the test image Z. Most of the angle values are out of the upper and lower bounds of the threshold values. This means that the test image Z is correctly classified as being an NA. The comparative analysis of intra-class vs. inter-class matching for NA detection shows that the NA classifier can produce good accuracy on the datasets used for the study, even though SURF features are scale and rotation-invariant. This is because the NA classifier uses additional information about the geometry of the local physical structures to detect NAs.

## V.   DISCUSSION

The Nearest Angle (NA) classifier demonstrates promising performance for handwritten text recognition (HTR) tasks across a diverse range of datasets, including Tamil, Telugu, and Devanagari. Several key observations can be made from the study:

Superiority over Traditional Classifiers: The NA classifier consistently outperforms traditional machine learning methods such as k-N), k-means clustering, SVM, and decision trees in terms of accuracy, sensitivity, specificity, and F1-score. This highlights its potential as a robust and efficient classifier for HTR tasks.

Comparison with Deep Learning Models: While deep learning architectures such as VGG-19 and MobileNet marginally surpass the NA classifier in terms of accuracy, they do so at the expense of computational efficiency. The NA classifier's rapid classification time presents an optimal trade-off between speed and accuracy, especially critical for resource-constrained devices and real-time applications.

Reliability across Datasets: The NA classifier's consistent performance across Tamil, Telugu, and Devanagari datasets underscores its generalizability. This versatility is essential for a classifier, especially in applications where diverse scripts might be encountered.

Intra-class vs. Inter-class Matching: The comparative analysis on intra-class and inter-class matching reinforces the NA classifier's robustness. By exploiting the geometry of local physical structures, the NA classifier effectively differentiates between characters that may look visually similar, thereby minimizing false matches.

Thresholding in NA: The use of threshold values ($\theta uan=100$ and $\theta lan=80$) for angle classification serves as a vital mechanism for the NA classifier. As the presented figures depict, the chosen thresholds enable effective discrimination between intra-class and inter-class matches. The robustness of these thresholds in classifying the characters accurately showcases the model's resilience to typical variances seen in handwritten data.

Potential for Real-World Applications: Given its quick classification time, combined with high accuracy, the NA classifier is particularly suited for real-world scenarios, especially those demanding swift recognition such as mobile OCR applications or real-time transcription services.

## VI. Conclusion

Local feature detectors and descriptors are powerful in many object recognition tasks. The complexity of deep-learning-based approaches can be avoided by using effective local descriptors such as SURF for feature extraction. In this study, the concept of local feature detection along with a similarity-voting-based classifier is introduced at the local level and a ranking-based classifier at the global level. The proposed Nearest Angles classifier is applied effectively with SURF descriptors for handwritten character recognition of Tamil, Devanagari, and Telugu scripts. With a slight compromise in the recognition accuracy, the proposed method facilitates the features of variable length as well as high dimensionality and reduces complexity. Benchmark databases are used to demonstrate robust recognition performance.

The usage of the collective class similarity score produces excellent results in the NA classifier as the false similarities are removed by selecting the IPs based on the angles between them. NA handles high dimensionality and variable-length feature vectors (IPs of training images). The study proves that local feature descriptors extract a huge number of informative features and can produce good results if used wisely with an efficient classifier. The proposed method utilizes local decision-making to reduce the computational overhead and achieves high classification accuracy rates of 91.0% for Tamil, 94.7% for Devanagari, and 88% for Telugu handwritten character datasets.

The capabilities of HCR systems can be improved in several ways. Transfer learning can be used to transfer knowledge from one script to another, which can reduce the need for large script-specific datasets. Additionally, HCR systems can be adapted for online recognition, allowing for real-time processing and feedback. This would be useful for applications such as digital signature verification and interactive systems. These enhancements would make HCR systems more adaptable, precise, and user-friendly, which would expand their usefulness in a variety of domains.

### References

[1] J. Nockels, P. Gooding, S. Ames, and M. Terras, "Understanding the application of handwritten text recognition technology in heritage contexts: a systematic review of Transkribus in published research," Archival Science, vol. 22, no. 3, pp. 367–392, Jun. 2022.

[2] A. Chaudhuri, K. Mandaviya, P. Badelia, and S. K Ghosh, "Optical Character Recognition Systems for Different Languages with Soft Computing", Cham: Springer International Publishing, pp. 1-7, 2017.

[3] R. Shah, M. K. Gupta and A. Kumar, "Ancient Sanskrit Line-level OCR using OpenNMT Architecture," 2021 Sixth International Conference on Image Information Processing (ICIIP), Shimla, India, pp. 347-352, 2021.

[4] C. Vasantha Lakshmi and C. Patvardhan, "A high accuracy OCR system for printed Telugu text," TENCON 2003. Conference on Convergent Technologies for Asia-Pacific Region, Bangalore, India, vol. 2, pp. 725-729, 2003.

[5] R. Saluja, D. Adiga, P. Chaudhuri, G. Ramakrishnan and M. Carman, "Error Detection and Corrections in Indic OCR Using LSTMs," 2017 14th IAPR International Conference on Document Analysis and Recognition (ICDAR), Kyoto, pp. 17-22, 2017.

[6] S. J. Basha, D. Veeraiah, G. Pavani, S. T. Afreen, P. Rajesh and M. S. Sasank, "A Novel Approach for Optical Character Recognition (OCR) of Handwritten Telugu Alphabets using Convolutional Neural Networks," 2021 Second International Conference on Electronics and Sustainable Communication Systems (ICESC), Coimbatore, India, pp. 1494-1500, 2021.

[7] C. S. Anoop and A. G. Ramakrishnan, "Meta-Learning for Indian Languages: Performance Analysis and Improvements With Linguistic Similarity Measures," in IEEE Access, vol. 11, no. 8, pp. 82050-82064, 2023.

[8] L. Alzubaidi, J. Zhang, A.J. Humaidi, A. Al-Dujaili, Y. Duan, O. Al-Shamma, J. Santamaría, , M.A Fadhel, , M. Al-Amidie, L. Farhan, "Review of deep learning: concepts, CNN architectures, challenges, applications, future directions," Journal of Big Data, vol. 8, no. 1, pp. 1-74. 2021.

[9] L. Chen, S. Li, Q. Bai, J. Yang, S. Jiang, and Y. Miao, "Review of Image Classification Algorithms Based on Convolutional Neural Networks," Remote Sensing, vol. 13, no. 22, pp. 4712, 2021.

[10] I. H. Sarker, "Deep Learning: A Comprehensive Overview on Techniques, Taxonomy, Applications and Research Directions," SN Computer Science, vol. 2, no. 6, pp. 1-20, 2021.

[11] I. Rodriguez-Conde, C. Campos, and F. Fdez-Riverola, "Optimized convolutional neural network architectures for efficient on-device vision-based object detection," Neural Computing and Applications, vol. 33, no. 23, pp. 10469–10501, 2021.

[12] C. Chen, P. Zhang, H. Zhang, J. Dai, H. Zhang, Y. Zhang, "Deep Learning on Computational-Resource-Limited Platforms: A Survey," Mobile Information Systems, vol. 2020, no. 6, pp. 1–19, 2020.

[13] S. Zhong, Y. Liu, and Q. Chen, "Visual orientation inhomogeneity based scale-invariant feature transform," Expert Systems with Applications, vol. 42, no. 13, pp. 5658–5667, 2015.

[14] . Guo, R. Xie and G. Jin, "An Efficient Method for NMR Data Compression Based on Fast Singular Value Decomposition," in IEEE Geoscience and Remote Sensing Letters, vol. 16, no. 2, pp. 301-305, 2019.

[15] J. Chai, H. Zeng, A. Li, and E. W. T. Ngai, "Deep learning in computer vision: A critical review of emerging techniques and application scenarios," Machine Learning with Applications, vol. 6, pp. 100134, Aug. 2021.

[16] B. Shah and H. Bhavsar, "Time Complexity in Deep Learning Models," Procedia Computer Science, vol. 215, pp. 202–210, 2022.

[17] S. Dargan, M. Kumar, M. R. Ayyagari, and G. Kumar, "A Survey of Deep Learning and Its Applications: A New Paradigm to Machine Learning," Archives of Computational Methods in Engineering, vol. 26, no. 3, pp. 1071–1092, 2019.

[18] A. Khan, A. Sohail, U. Zahoora, and A. S. Qureshi, "A survey of the recent architectures of deep convolutional neural networks," Artificial Intelligence Review, vol. 53, pp. 5455–5516, 2020.

[19] M. Rai and P. Rivas, "A Review of Convolutional Neural Networks and Gabor Filters in Object Recognition," 2020 International Conference on Computational Science and Computational Intelligence (CSCI), Las Vegas, NV, USA, pp. 1560-1567, 2020.

[20] A. M. Elmoogy, X. Dong, T. Lu, R. Westendorp and K. R. Tarimala, "SurfCNN: A Descriptor Accelerated Convolutional Neural Network for Image-Based Indoor Localization," in IEEE Access, vol. 8, pp. 59750-59759, 2020.

[21] S. Katoch, V. Singh, and U. S. Tiwary, "Indian Sign Language recognition system using SURF with SVM and CNN," Array, vol. 14, pp. 100141, 2022.

[22] H. Bay, T. Tuytelaars, and Luc Van Gool, "SURF: Speeded Up Robust Features," in Computer Vision – ECCV 2006, pp. 404–417, 2006.

[23] C. Li, L. Khan, and B. Prabhakaran, "Feature Selection for Classification of Variable Length Multiattribute Motions," Springer eBooks, pp. 116-137, 2007.

[24] S. Bandyopadhyay, C. A. Murthy, and S. K. Pal, "Pattern classification using genetic algorithms: Determination of H," Pattern Recognition

Letters, vol. 19, no. 13, pp. 1171–1181, 1998.

[25] A. D. R. Nelson and R. R. Rao, "A modified GA classifier for offline Tamil handwritten character recognition," International Journal of Applied Pattern Recognition, vol. 4, no. 1, pp. 89, 2017.

[26] H. Kim, E. Ahn, M. Shin, and S.-H. Sim, "Crack and Noncrack Classification from Concrete Surface Images Using Machine Learning," Structural Health Monitoring, vol. 18, no. 3, pp. 725–738, 2018.

[27] A. Utomo, E. F. Juniawan, V. Lioe, and D. D. Santika, "Local Features Based Deep Learning for Mammographic Image Classification: In Comparison to CNN Models," Procedia Computer Science, vol. 179, pp. 169–176, 2021.

[28] N. Bhatia, "Survey of Nearest Neighbor Techniques," IJCSIS) International Journal of Computer Science and Information Security,

vol. 8, no. 2, pp.302-305, 2010.

[29] M. E. Houle, H. Kriegel, Peer Kröger, E. Schubert, and A. Zimek, "Can Shared-Neighbor Distances Defeat the Curse of Dimensionality?," Lecture Notes in Computer Science, pp. 482–500, 2010.

[30] A. P. James and S. Dimitrijev, "Nearest Neighbor Classifier Based on Nearest Feature Decisions," The Computer Journal, vol. 55, no. 9, pp. 1072–1087, Feb. 2012.

[31] H. Bay, T. Tuytelaars, and Luc Van Gool, "SURF: Speeded Up Robust Features," in Computer Vision – ECCV 2006, pp. 404–417, 2006.

[32] R. N. Ashlin Deepa and R. Rajeswara Rao, "A novel nearest interest point classifier for offline Tamil handwritten character recognition," Pattern Analysis and Applications, vol. 4, no. 23, pp. 199–212, 2020.

# Recyclable Waste Classification using SquezeeNet and XGBoost

Intan Nurma Yulita[1*], Firman Ardiansyah[2], Anton Satria Prabuwono[3], Muhammad Rasyid Ramdhani[4],
Mokhamad Arfan Wicaksono[5], Agus Trisanto[6], Asep Sholahuddin[7]

Department of Computer Science, Universitas Padjadjaran, Sumedang, Indonesia[1, 7]
Magister of Management, Institut Teknologi dan Bisnis Ahmad Dahlan Lamongan, Indonesia[2]
Faculty of Computing and Information Technology in Rabigh, King Abdulaziz University, Rabigh, Saudi Arabia[3]
Department of Electrical Engineering, Universitas Padjadjaran, Sumedang, Indonesia[4, 6]
Bachelor of Software Engineering Technology, Akademi Digital Bandung, Indonesia[5]

*Abstract*—The unregulated buildup of waste results in the occurrence of flames. This phenomenon poses a substantial threat to both the ecological system and human welfare. To tackle this problem, the current study proposes the implementation of Machine Learning technology to automate the sorting of waste. The methodology being examined incorporates the utilization of SqueezeNet as an image embedding method in conjunction with XGBoost as the final classifier. This work examines the efficacy of the aforementioned technique by doing a comparative analysis with many alternative final classifiers, including LightGBM, XGBoost, CatBoost, Random Forest, SVM, Naïve Bayes, KNN, and Decision Tree. The experimental results indicate that the integration of SqueezeNet and XGBoost produces the highest level of performance in the field of garbage categorization, as supported by an F1-score of 0.931. SqueezeNet is a method employed for image embedding that enables the extraction of salient features from images. This procedure enables the recognition of unique characteristics linked to different classes. Therefore, XGBoost may be utilized to enhance classification tasks. XGBoost has the ability to generate a feature importance score. Therefore, enabling the recognition of the most prominent attributes. This methodology possesses the capacity to alleviate the risk of fire that arises due to the accumulation of unregulated trash. This work makes a substantial contribution to environmental conservation and the improvement of public safety.

*Keywords*—*Garbage classification; image; machine learning; SqueezeNet; XGBoost*

## I. INTRODUCTION

Landfill fires are caused by human and environmental factors [1]. Uncontrolled burning causes flames. When heated, plastic, paper, and biological materials can catch fire. Due to the high population, a fire from a pile of waste spreads quickly and uncontrollably, making containment difficult. Chemical reactions can occur in hot and humid situations [2], [3], especially in areas where organic waste decomposes, generating heat and fire-starting gases. Fermentation and breakdown can produce methane. Direct sunlight and extreme temperatures can heat gathered rubbish [4-5]. The risk of fire increases when waste contains combustible materials. When mixed, hazardous trash like solvents, batteries, and other poisons can create heat or burn. Sometimes exterior fires, maybe caused by humans, enter the building. For instance,

illegally incinerated garbage [6-8] or environmental components like embers from nearby forest fires. These sites release toxic gases like methane. In the presence of an igniting source and a gas leak, a fire may occur. Environmental factors including high winds and severe weather might affect fire growth [9–11]. Strong winds may help a fire spread quickly. Fires in this area harm the environment, health, and infrastructure. Thus, garbage segregation and other waste management measures are crucial.

The field deployment of garbage segregation has numerous hurdles that may hinder waste management programs [12–14]. Public comprehension of waste segregation and its environmental benefits is sometimes lacking. Educational and socialization efforts are needed to raise awareness of waste segregation. Additionally, many places lack the capacity to segregate trash. Without separate receptacles, recycling infrastructure, and clear instructions, waste segregation may be difficult. Trash segregation by communities may not guarantee long-term landfill diversion without proper recycling facilities. Without recycling facilities, rubbish sorting may be less appealing. Insufficient or inaccurate waste sorting may reduce sorting efficiency. Recycling is difficult when separated items are mixed together.

Efficient and effective waste segregation technology has several benefits for waste management and environmental preservation. Advanced sorting technology can precisely separate various materials. Segregating materials improves recycling efficiency and produces higher-quality products. By using good segregation technology, landfill garbage may be reduced [15]. This approach extends landfill life and reduces habitat damage. Effective waste segregation reduces environmental deterioration, especially soil and water pollution. Sorting technology separates pollutants to protect ecosystems and human health. Manual sorting is laborious and error-prone. Sorting technology can improve material separation and save manual labor, solving the problem.

Technology has improved segregation precision and consistency, exceeding hand sorting. Organic trash, including food scraps, leaves, and other biodegradable materials, may be distinguished from recyclable garbage like plastic, paper, and metal with great precision [16–21]. Implementing waste separation techniques requires a categorization system that can

independently distinguish organic and recyclable components. The merging of computer vision and artificial intelligence (AI) has improved rubbish categorization precision and efficacy [22]. The seamless integration of these two sophisticated technologies allows the system to independently identify and classify waste items. Computer vision is an academic field that lets computers view and understand visual data like images and movies like humans [23-27]. Computer vision systems can recognize trash items' unique traits. Advanced cameras and optical sensors enable discernment by effectively examining and interpreting color, shape, and texture. Additionally, it shows the capacity to critically evaluate a variety of visual representations and data from different angles. A powerful image processing algorithm allows the system to distinguish patterns, characteristics, and qualities that distinguish organic from recyclable trash. Artificial intelligence, especially machine learning, is crucial to trash categorization.

Machine learning algorithms may learn from training data, allowing them to recognize and understand patterns and make accurate classification judgments [28]. Computer vision and AI require model training for categorization. This complex procedure uses massive quantities of sample images and waste material data. By using many samples, the model can identify biological waste from recyclable waste. The trained model can automatically and instantly categorize garbage after training. The process uses a camera or optical sensor to capture an image of the garbage. An artificial intelligence algorithm then analyzes the image and accurately classifies the garbage.

Convolutional Neural Networks (CNNs) are highly effective in processing image data [29–31]. This neural network uses convolutional layers to identify complex visual properties from a garbage image and categorize it by kind. Large amounts of data are needed to train CNN models. However, training data is sometimes limited, especially for specialized or rare image recognition assignments. To overcome deep neural network model training challenges, transfer learning in CNNs has become a feasible option. Transfer learning lets you use pre-trained models on large datasets to solve new problems using small datasets. Training multi-layer deep CNN models requires a lot of time, computer resources, and complex optimization methods. Transfer learning is a popular machine learning approach that uses pre-trained models to speed up model training. Using an existing model as a starting point reduces the time and computing resources needed to train a model from scratch.

SqueezeNet, a neural network architecture designed for image recognition, contains fewer parameters than AlexNet, VGG, and ResNet [32-34]. The SqueezeNet framework develops models with low parameter counts and great image recognition accuracy. SqueezeNet extracts visual features, which other approaches use as embedding representations. SqueezeNet embeds images by condensing visual input into numbers. This altered representation can help machine learning systems classify rubbish.

Bai studied garbage classification [35]. Machine vision, item recognition, and check categorization are performed sequentially. The hierarchical system development framework uses Struts2, spring, and Hibernate. Optical identification,

convolutional neural networks, and Naive Bayes are crucial garbage categorization technologies. Ghanshala et al. use machine learning to categorize areas into two categories: garbage-free and high-garbage-filled [36]. The study used four algorithms, achieving 98.6% accuracy with kNN and Naïve Bayes, 85.4% with Decision Tree, and 98.4% with Random Forest.

Another classification has been done using Histogram of Oriented Gradients (HOG) features and an SVM boosting algorithm [37]. The submitted image is preprocessed to improve recognition. A HOG is used to extract properties. The classification device is trained to send relevant data to the image set. From this premise, the categorization scenario is identified. The algorithm's classification accuracy is 95% or better, a 10% improvement over the single SVM classification strategy. The garbage classification method is accurate and practical.

The current work suggests utilizing XGBoost as the final classifier once SqueezeNet features are generated. XGBoost, or Extreme Gradient Boosting, is a popular categorization machine learning approach. The ensemble technique combines predictions from numerous simpler machine learning models, known as "weak learners," to improve accuracy and resilience. The system automatically identifies and categorizes various waste materials into two classes (organic, and recyclable) using these two advanced technologies.

## II. MATERIAL AND METHODS

The approach employed in the present study can be seen in Fig. 1. Furthermore, this study not only implemented the suggested method but also did a comparison with alternative methods.
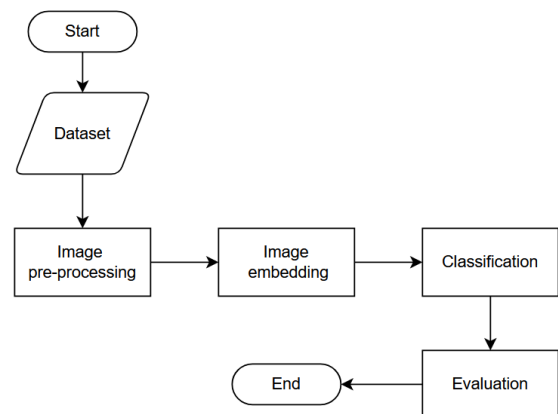


Fig. 1. Research methodology.

### A. Dataset Collection

The dataset employed in this study was provided by Sashaank Sekar. The data may be accessed from the following source: https://www.kaggle.com/techsash/waste-classification-data. The initial dataset obtained from Kaggle has a total of 25,077 images, with 13,966 images depicting organic materials and 11,111 images representing recyclable materials. The images obtained are in the form of colored .jpg files, displaying a variety of portrait and landscape orientations. The resolution

of these imagegraphs varies, with a minimum of 191 pixels and a high of 264 pixels.

### B. SquezeeNet

SqueezeNet serves as a technique for producing image embeddings through the process of extracting features from images [31]. This stage involved running images through the convolution and pooling layers inside the SqueezeNet model, afterward extracting the output from one of these layers as a feature representation, also known as an embedding, of the image. The mechanism can be described as follows:

- Image preprocessing

It involves applying several techniques to prepare images in a dataset for further analysis. These techniques include pixel intensity normalization, resizing, and noise reduction, among others. The purpose of image preprocessing is to ensure that the images meet specific requirements and are ready for further analysis tasks.

- Feature extraction

It employs pre-processed images as the input data for the SqueezeNet architecture. The process involves passing images through convolutional and pooling layers inside the SqueezeNet architecture.

- Embedding layer

It designs a certain layer inside SqueezeNet as the desired location for extracting the feature representation (embedding) of the image. The inclusion of this layer is recommended prior to the implementation of the fully linked layers.

- Feature representation

It obtains feature representations involves passing images through the SqueezeNet architecture until a certain layer is reached, resulting in a vector representation of the image's features, also known as embeddings.

- Feature vectors

The vector can serve as image embeddings by utilizing the feature representation vectors derived from the preceding stage. These vectors were utilized as input in XGBoost, to perform the classification task.

### C. XGBoost

XGBoost, also known as Extreme Gradient Boosting, is a commonly employed machine learning method that is particularly recognized for its effectiveness in classification problems [38-40]. The method in issue can be classified as a type of ensemble learning technique, wherein the outcomes of several smaller and less powerful models are combined to create a more robust model. XGBoost places emphasis on employing decision trees as its foundational model, while integrating the principles of gradient boosting and regularized regression to get exceptional performance across diverse tasks. Fig. 2 illustrates a simplified version of XGBoost. The components of XGBoost are as follows:

- Decision Trees

The method employed as the fundamental model in XGBoost. A decision tree is a hierarchical arrangement comprising of nodes and branches, which symbolize decisions or predictions made at each node.

- Gradient Boosting

XGBoost employs an ensemble learning technique with gradient boosting methodology. Initially, a preliminary (suboptimal) model is constructed, often in the form of a basic decision tree. Subsequently, a subsequent model is constructed with the purpose of addressing the errors committed by its predecessor. This procedure is iteratively conducted, with particular attention on data points that demonstrate persistent prediction mistakes.

- Boosting

In the context of XGBoost, the model addition process involves the incremental inclusion of a new decision tree into the existing ensemble at each iteration. The proposed model aims to predict the residual, which refers to the difference between the observed target value and the current representation, based on the preceding model.

- Penalty and Regularization

The XGBoost algorithm incorporates regularization techniques to enhance the performance of the decision trees it constructs. The successful completion of this job is helped by the utilization of an objective function that integrates objective regression alongside a penalty function, often L1 or L2, to mitigate the problem of overfitting.
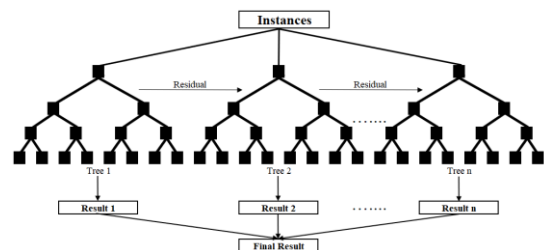


Fig. 2. Flowchart of XGBoost.

XGBoost possesses different benefits in comparison to other algorithms due to its unique operating mechanism. The XGBoost algorithm is a machine learning methodology that integrates regularization methods to effectively mitigate the problem of overfitting. The objective of this approach in this study was to develop models that demonstrate enhanced generalization and less sensitivity to the specific attributes of the training data. The XGBoost technique, which is widely used in machine learning, offers a wide range of hyperparameters that may be tuned to enhance the performance of the model. Furthermore, the failure to get the ideal value for the hyperparameter might be seen as an adverse result.

### D. Evaluation

To optimize the evaluation process, it is imperative to partition the dataset into distinct subsets, namely a training set and a testing set [41]. The current study leveraged a dataset of considerable scale, thereby justifying the adoption of a five-fold cross-validation methodology. The utilization of cross-

validation (CV) is a widely adopted methodology within the realm of machine learning for the purpose of evaluating the performance and effectiveness of prediction models [42]. The proposed methodology involves partitioning the provided dataset into multiple distinct subsets, commonly referred to as folds. This approach aims to assess the generalization capabilities of the model by simulating real-world scenarios where the model encounters novel data samples [43]. In each iteration of the experiment, a single fold is designated as the testing set, while the remaining four folds are allocated as the training set. In each iteration, it is imperative to compute the evaluation metric. Upon the completion of the five iterations, it becomes imperative to calculate the mean value of the evaluation metrics acquired throughout each iteration.

The present study incorporates a comprehensive set of evaluation metrics, namely accuracy, precision, recall, and the F1 score. The accuracy is computed by dividing the number of correctly classified instances by the total number of instances in the dataset. This ratio provides a clear representation of the model's ability to correctly classify data points. In such scenarios, relying solely on accuracy as an evaluation metric may introduce bias. The metric of precision is employed as a quantitative measure to evaluate the degree of accuracy exhibited by a model in generating positive predictions. The notion of recall is a fundamental aspect within the realm of machine learning, which concerns the model's capacity to effectively recognize and encompass all instances that are genuinely positive. The computation of the F1 score involves the utilization of the harmonic mean to combine accuracy and recall metrics. By calculating the harmonic mean of these two measures, the F1 score ensures a balanced evaluation, assigning equal importance to both accuracy and recall.

This study aim to conduct a comprehensive comparison between the SqueezeNet combination and an alternative final classifier, distinct from the widely used XGBoost algorithm. The objective is to evaluate the performance and efficacy of these two approaches in the context of machine learning. By undertaking this comparative analysis, it seek to shed light on the relative strengths and weaknesses of these methodologies, thereby contributing to the existing body of knowledge in the field of machine learning research. In the realm of machine learning, a multitude of algorithms have emerged as prominent contenders for various tasks. Among these algorithms, Random Forest, SVM with a Radial Basis Function (RBF) kernel, Naïve Bayes, K-Nearest Neighbor (KNN) with a value of K equal to 5, and Decision Tree have garnered significant attention and utilization. Random Forest, a versatile ensemble learning method, has proven to be highly effective in tackling classification and regression problems. By constructing a multitude of decision trees and aggregating their predictions, Random Forest mitigates overfitting and enhances generalization capabilities. SVM, a powerful algorithm for both classification and regression tasks, utilizes a kernel function to map data into higher-dimensional feature spaces. The RBF kernel, in particular, has exhibited remarkable performance in capturing complex relationships within data, enabling SVM to excel in diverse problem domains. Naïve Bayes, a probabilistic classifier, leverages Bayes' theorem with the assumption of feature independence. Despite its simplistic

nature, Naïve Bayes has demonstrated remarkable efficiency and effectiveness, making it a popular choice for text classification and spam filtering tasks. KNN is a non-parametric algorithm that classifies data points based on the majority vote of their K nearest neighbors. With K set to 5, KNN strikes a balance between capturing local patterns and avoiding excessive noise, rendering it a valuable tool in pattern recognition and recommendation systems. In addition to the aforementioned Boosting variants, it is worth noting the existence of several other implementations in the field. Notably, two prominent examples are the Light Gradient Boosting Machine (LightGBM) and CatBoost, which both leverage the power of Gradient Boosting in conjunction with Decision Trees.

## III. RESULTS AND DISCUSSION

Tables I, II, and III provide a comprehensive overview of the performance metrics associated with the algorithms employed for the classification of organic, recyclable, and mixed wastes. The three tables demonstrate that the suggested method shows superior performance. The many variations of Boosting, including LightGBM, XGBoost, and CatBoost, exhibit superior performance with the K-Nearest Neighbors (KNN) algorithm.

TABLE I.    THE AVERAGE PERFORMANCE OF EACH FINAL CLASSIFIER FOR THE "ORGANIC" CLASS DATA WAS EVALUATED

| Final Classifier | Accuracy | Precision | Recall | F1 Score |
|---|---|---|---|---|
| LightGBM | 0.912 | 0.917 | 0.926 | 0.921 |
| XGBoost | 0.931 | 0.935 | 0.942 | 0.939 |
| CatBoost | 0.925 | 0.931 | 0.934 | 0.932 |
| Random Forest | 0.893 | 0.890 | 0.922 | 0.906 |
| SVM | 0.706 | 0.672 | 0.924 | 0.778 |
| Naïve Bayes | 0.844 | 0.870 | 0.845 | 0.857 |
| KNN | 0.921 | 0.916 | 0.944 | 0.930 |
| Decision Tree | 0.859 | 0.866 | 0.884 | 0.875 |

The performance of the system achieved a score over 0.9 for all assessment parameters. Despite being lightweight convolutional neural network (CNN) architecture, SqueezeNet had remarkable proficiency in extracting features from image input. It implies that the features produced by SqueezeNet may possess greater informativeness and relevance compared to features provided by alternative models. Ensemble models, like LightGBM, XGBoost, and CatBoost, provide the ability to enhance overall performance by combining predictions from a limited set of basic models represented as decision trees.

TABLE II.    THE AVERAGE PERFORMANCE OF EACH FINAL CLASSIFIER FOR THE "RECYCLABLE " CLASS DATA WAS EVALUATED

| Model: R | Accuracy | Precision | Recall | F1 Score |
|---|---|---|---|---|
| LightGBM | 0.912 | 0.906 | 0.894 | 0.900 |
| XGBoost | 0.931 | 0.926 | 0.918 | 0.922 |
| CatBoost | 0.925 | 0.917 | 0.913 | 0.915 |
| Random Forest | 0.893 | 0.897 | 0.857 | 0.877 |
| SVM | 0.706 | 0.819 | 0.433 | 0.567 |
| Naïve Bayes | 0.844 | 0.812 | 0.842 | 0.827 |
| KNN | 0.921 | 0.927 | 0.891 | 0.909 |
| Decision Tree | 0.859 | 0.850 | 0.829 | 0.839 |

TABLE III.    THE AVERAGE PERFORMANCE OF EACH FINAL CLASSIFIER FOR ALL CLASS DATA WAS EVALUATED

| Model: All | Accuracy | Precision | Recall | F1 Score |
|---|---|---|---|---|
| LightGBM | 0.912 | 0.912 | 0.912 | 0.912 |
| XGBoost | 0.931 | 0.931 | 0.931 | 0.931 |
| CatBoost | 0.925 | 0.925 | 0.925 | 0.925 |
| Random Forest | 0.893 | 0.893 | 0.893 | 0.893 |
| SVM | 0.706 | 0.737 | 0.706 | 0.684 |
| Naïve Bayes | 0.844 | 0.844 | 0.844 | 0.844 |
| KNN | 0.921 | 0.921 | 0.921 | 0.920 |
| Decision Tree | 0.859 | 0.859 | 0.859 | 0.839 |

TABLE IV.    THE CONFUSION MATRIX WAS DERIVED FROM THE INTEGRATION OF SQUENZEENET AND LIGHTGBM MODELS

| | | Predicted | |
|---|---|---|---|
| | | O | R |
| Actual | O | 12936 | 1030 |
| | R | 1174 | 9937 |
| | Total | 14110 | 10967 |

TABLE V.    THE CONFUSION MATRIX WAS DERIVED FROM THE INTEGRATION OF SQUENZEENET AND XGBOOST MODELS

| | | Predicted | |
|---|---|---|---|
| | | O | R |
| Actual | O | 13150 | 816 |
| | R | 907 | 10204 |
| | Total | 14057 | 11020 |

Mechanisms such as boosting were employed to adaptively assign greater weight to samples that pose challenges in recognition, hence enhancing the system's capacity to effectively process intricate data. By engaging in mistake correction and prioritizing the analysis of challenging samples, individuals could enhance their proficiency in data classification. The utilization of secondary information obtained by decision trees in the boosting process is a common practice in boosting models. One potential approach is to incorporate the weight or score assigned to each tree in order to arrive at a conclusive determination. This intervention has the potential to enhance the overall efficacy of the model. The optimization of the parameters in this study led to the development of a model that effectively aligns with the observed data. The integration of SqueezeNet as a feature extractor with a boosting algorithm facilitated the combination of the robust feature extraction skills inherent in convolutional neural networks (CNNs) with the powerful ensemble capabilities offered by the boosting method. In contrast, the K-nearest neighbors (KNN) method employed in this work was classified as an instance-based approach, wherein the selection of K values determines the appropriate number of neighboring instances.

TABLE VI.    THE CONFUSION MATRIX WAS DERIVED FROM THE INTEGRATION OF SQUENZEENET AND CATBOOST MODELS

| | | Predicted | |
|---|---|---|---|
| | | O | R |
| Actual | O | 13042 | 924 |
| | R | 966 | 10145 |
| | Total | 14008 | 11069 |

TABLE VII.    THE CONFUSION MATRIX WAS DERIVED FROM THE INTEGRATION OF SQUENZEENET AND RANDOM FOREST MODELS

| | | Predicted | |
|---|---|---|---|
| | | O | R |
| Actual | O | 12876 | 1090 |
| | R | 1585 | 9526 |
| | Total | 14461 | 10616 |

TABLE VIII.    THE CONFUSION MATRIX WAS DERIVED FROM THE INTEGRATION OF SQUENZEENET AND SVM MODELS

| | | Predicted | |
|---|---|---|---|
| | | O | R |
| Actual | O | 12905 | 1061 |
| | R | 6300 | 4811 |
| | Total | 19205 | 5872 |

The utilization of SqueezeNet as a feature extractor for further application by classification models like Random Forest, Naïve Bayes, or Decision Tree encounters many obstacles that might potentially impact the performance of those models. CNN designs, such as SqueezeNet, often generate feature representations that possess quite large dimensions. The utilization of high-dimensional characteristics in models such as Random Forest, Naïve Bayes, or Decision Tree gives rise to a circumstance known as the "curse of dimensionality." This phenomenon implies that when the number of features is enormous, the potential sample space needed to generate accurate estimates grows much more expansive. Consequently, the models encounter difficulties in identifying pertinent patterns from the data, as evidenced by the findings of this study. The interdependence among the features produced by SqueezeNet is substantial, potentially leading to the confusion of outcomes in models that assume feature independence, such as Naïve Bayes. The performance of these models will be enhanced in cases when the characteristics exhibit a high degree of independence. The efficacy of a classification model is heavily influenced by the inherent attributes of the data employed. If the data has an apparent pattern that is more compatible with straightforward models or does not need very intricate feature representation, then models such as Random Forest, Naïve Bayes, or Decision Tree may be more appropriate. The intricate characteristics examined in this study were attributed as the underlying factor for the ineffectiveness of these algorithms non the categorization process. However, this was also due to the fact that these algorithms had not yet been calibrated with specific parameters.

TABLE IX.    THE CONFUSION MATRIX WAS DERIVED FROM THE INTEGRATION OF SQUENZEENET AND NAÏVE BAYES MODELS

| | | Predicted | |
|---|---|---|---|
| | | **O** | **R** |
| Actual | O | 11801 | 2165 |
| | R | 1759 | 9352 |
| | Total | 13560 | 11517 |

The study evaluated the performance of various machine learning methods. The Support Vector Machine (SVM) approach exhibited the lowest performance across all three tables. The attainment of precise classification frequently necessitates the inclusion of superior and discerning features. In the context of machine learning, it is imperative to ensure that the features extracted from a given model, such as SqueezeNet, effectively capture the salient and discriminative characteristics relevant to a specific task. Failure to achieve this may result in a detrimental impact on the performance of subsequent classification algorithms, such as Support Vector Machines (SVMs). The potential exists for SqueezeNet and Support Vector Machines (SVM) to demonstrate dissimilar scales in relation to the distribution of feature values. Introduction: In the context of machine learning, the issue of scaling mismatch has been identified as a potential challenge that can adversely affect the performance of Support Vector Machines (SVM). This research report aims to explore the difficulties that may arise due to scaling mismatch and the subsequent impact on the performance of SVM. Scaling Mismatch: Scaling mismatch refers to the situation where the scales of different features in a dataset are not aligned. In other words, the range or magnitude of values for different features varies significantly. This discrepancy in scaling can To mitigate the aforementioned concern, it is imperative to incorporate normalization or scaling methodologies. The performance of Support Vector Machines (SVMs) is significantly impacted by the selection of hyperparameters, which encompass the penalty parameter (C) and the kernel type. The observed suboptimal performance can potentially be attributed to the presence of inaccurate hyperparameter configurations. The impact of data type on the performance of Support Vector Machines (SVM) for model training was found to be statistically significant. The efficacy of Support Vector Machines (SVM) may be influenced by the congruity between the training data employed for generating the embedding and the data that necessitates categorization. The present study investigates the impact of SVM parameter values on its ability to handle complex data. The findings reveal that the utilization of certain parameter values in SVM leads to diminished efficacy in effectively handling intricate datasets.

TABLE X.    THE CONFUSION MATRIX WAS DERIVED FROM THE INTEGRATION OF SQUENZEENET AND KNN MODELS

| | | Predicted | |
|---|---|---|---|
| | | **O** | **R** |
| Actual | O | 13189 | 777 |
| | R | 1215 | 9896 |
| | Total | 14404 | 10673 |

TABLE XI.    THE CONFUSION MATRIX WAS DERIVED FROM THE INTEGRATION OF SQUENZEENET AND DECISION TREE MODELS

| | | Predicted | |
|---|---|---|---|
| | | **O** | **R** |
| Actual | O | 12343 | 1623 |
| | R | 1902 | 9209 |
| | Total | 14245 | 10832 |

In relation to the evaluation of algorithm performance in this work, the confusion matrix is employed as a metric to assess and comprehend the efficacy of the used Machine Learning algorithm in classification. This matrix facilitates an in-depth evaluation of the algorithm's performance, providing a deeper understanding of the model's strengths and limitations within the scope of this study. The confusion matrices for each method are displayed in Tables IV to Table XI. The table consists of a total of two rows and two columns. The initial row in the primary column displays instances of true positives (TP). The classification model accurately predicts occurrences that truly belong to the positive class. It refers to the count of instances where the model accurately predicted a good outcome and the actual result likewise turned out to be positive. The cell located at the intersection of the first row and the second column is referred to as false negative (FN). The model erroneously classifies occurrences that should belong to the positive class as negative. Put simply, it refers to the instances in which the model incorrectly predicted a negative outcome while the actual result was positive. The element located in the second row of the first column is classified as false positives (FP). The model erroneously classifies occurrences that should belong to the negative class as positive. It refers to the count of instances where the model made a positive prediction despite the actual outcome being negative. The cell located in the second row and second column represents the number of true negatives (TN). The categorization model accurately predicts occurrences that truly pertain to the negative class. It refers to the count of instances where the model made a negative prediction and the actual result was likewise negative.

The XGBoost and CatBoost classifiers demonstrated superior performance in accurately categorizing both organic and recyclable categories, with misclassified instances numbering less than 1000. The K-nearest neighbors (KNN) technique is considered to be one of the top three algorithms in machine learning. However, it has been shown that when used to certain datasets, especially those including recyclable classes, a significant number of misclassifications occur, with the misclassified instances exceeding 1000 in number. The data shown in Table VIII relates to the misclassification of the recyclable class in SVM specifically in cases where the achieved results exceeded 6000 data points. This numerical value exceeds the amount of accurately identified data.

## IV. CONCLUSION

This study proposes a comprehensive analysis of the significant consequences of uncontrolled garbage accumulation in initiating fires that have adverse effects on both the natural environment and human society. A unique solution has been developed to address this issue, employing Machine Learning techniques to autonomously segregate garbage through the

utilization of a highly efficient algorithm. The findings from the experimental analysis demonstrated that the utilization of SqueezeNet as an image recognition technique, coupled with XGBoost as the final classifier, emerges as the most optimal selection in the investigation, exhibiting exceptional performance.

This study also examined the effectiveness of SqueezeNet as a feature extractor in conjunction with a final classifier that differs from XGBoost. Various machine learning methods, including Random Forest, Support Vector Machine (SVM), Naïve Bayes, K-Nearest Neighbor (KNN), and Decision Tree, are commonly employed in the field of machine learning. The K-Nearest Neighbors (KNN) algorithm has exceptional performance, with a score exceeding 0.9 for all evaluation metrics. The lightweight convolutional neural network design of SqueezeNet enabled it to extract features that possess higher levels of informativeness and relevance in comparison to alternative models. Ensemble models such as LightGBM, XGBoost, and CatBoost improved overall performance by aggregating predictions from a restricted collection of fundamental models, which are typically shown as decision trees. Enhancing the system's ability to handle complex data may be achieved by the use of boosting techniques, such as error correction and prioritization of tough samples. The utilization of a confusion matrix was employed to assess the efficacy of a Machine Learning algorithm in the task of categorization. The classifiers XGBoost and CatBoost demonstrated exceptional performance in reliably classifying organic and recyclable categories, with a minimal number of misclassified examples, namely less than 1000. The K-nearest neighbors (KNN) approach, which is widely recognized as one of the leading algorithms, has been found to exhibit notable misclassifications in some datasets, notably in relation to recyclable classes.

The primary advantage of this research has great significance in addressing the issue of waste management. The use of automated trash segregation via Machine Learning techniques has the potential to mitigate the occurrence of fires, hence safeguarding ecosystems and infrastructure from detrimental impacts. Furthermore, the implementation of automated waste segregation has the potential to enhance operational effectiveness and safety within waste management systems, mitigate the likelihood of contamination, and contribute to the promotion of sustainable waste management practices. In addition, the utilization of this technology has the potential to mitigate the potential harm caused by human contact with dangerous compounds and foster ecological hygiene. Therefore, this research study significantly contributes to the preservation of the environment, mitigation of fire hazards, and enhancement of the community's quality of life. The utilization of Machine Learning technology, namely through the utilization of SqueezeNet and XGBoost, holds significant potential in the realm of automated waste segregation. This approach represents a crucial stride towards effectively tackling pressing waste-related issues and fostering sustainable advantages for both the society and environment.

## REFERENCES

[1] H. Fajkovic, et al., "Unsanitary Landfill Fires as a Source of a PCDD/Fs Contamination," Croatica Chemica Acta (9) No. 1, 2018.

[2] P. K. Ghodke, et al., "Experimental Investigation on Pyrolysis of Domestic Plastic Wastes for Fuel Grade Hydrocarbons," Processes (11) Nno. 1, 2023.

[3] L. A. Koroleva, et al., "Application of the Holt — Winters Model and the Exergetic Method for Predicting Safe Waste Management in the Russian Federation," Bezopasnost' Truda v Promyshlennosti (2021) No. 11, 2021.

[4] Z. Y. Yan et al., "Basic Features of Combustible Rural Garbage Component and Its Spatial-temporal Difference in China," Huanjing Kexue/Environmental Science (38) No. 7, 2017.

[5] S. Chen et al., "Carbon emissions under different domestic waste treatment modes induced by garbage classification: Case study in pilot communities in Shanghai, China," Science of the Total Environment(717), 2020.

[6] Saskatchewan Ministry of Environment, "EPB 433- Health and Environmental Effects of Burning Waste Plastics," Saskatchewan Ministry of Environment, 2012.

[7] P. Appleby, "3 Construction Waste Management," in Integrated Sustainable Design of Buildings, 2020.

[8] O. B. Ifeoluwa, "Harmful Effects and Management of Indiscriminate Solid Waste Disposal on Human and its Environment in Nigeria: A Review," Global Journal of Research and Review (6) No. 1, 2019.

[9] J. Stuivenvolt Allen, et al., "Three Western Pacific Typhoons Strengthened Fire Weather in the Recent Northwest U.S. Conflagration," Geophysical Research Letters (48) No. 3. 2021.

[10] N. J. Nauslar, J. T. Abatzoglou, and P. T. Marsh, "The 2017 north bay and southern california fires: A case study," Fire (1) No. 1, 2018.

[11] D. M. J. S. Bowman, et al., "The severity and extent of the Australia 2019–20 Eucalyptus forest fires are not the legacy of forest management," Nat Ecol Evol (5) No. 7, 2021.

[12] E. E. Coracero, et al., "A Long-Standing Problem: A Review on the Solid Waste Management in the Philippines," Indonesian Journal of Social and Environmental Issues (2) No. 3, 2021.

[13] R. Chauhan, et al., "Efficient Future Waste Management: A Learning-Based Approach with Deep Neural Networks for Smart System (LADS)," Applied Sciences (13) No. 7, 2023.

[14] G. J. Duine, L. M. V. Carvalho, and C. Jones, "Mesoscale patterns associated with two distinct heatwave events in coastal Santa Barbara, California, and their impact on local fire risk conditions," Weather Clim Extrem( 37), 2022.

[15] T. Thimmaiah, et al., "Waste Management in India: Challenges and Opportunities for Entrepreneurs," Interantional Journal of Scientific Research in Engineering and Management (7) No. 04, 2023.

[16] A. A. Bankole, et al., "Comparative Study of the Selective Sorption of Organic Dyes on Recyclable Materials—A Cost-Effective Method for Waste Treatment in Educational and Small Research Laboratories," Separations (9) No. 6, 2022.

[17] M. Prieto-Espinoza, B. Susset, and P. Grathwohl, "Long-Term Leaching Behavior of Organic and Recyclable Pollutants after Wet Processing of Solid Waste Materials," Materials (15) Nno. 3, 2022.

[18] U. Chadha et al., "A review of the function of using carbon nanomaterials in membrane filtration for contaminant removal from wastewater," Materials Research Expre (9) No. 1. 2022.

[19] A. K. Panda et al., "Impact of Vermicomposting on Greenhouse Gas Emission: A Short Review," Sustainability (14) No. 18. 2022.

[20] K. Boukayouht, L. Bazzi, and S. El Hankari, "Sustainable synthesis of metal-organic frameworks and their derived materials from organic and recyclable wastes," Coordination Chemistry Reviews (478), 2023.

[21] H. A. Mupambwa and P. N. S. Mnkeni, "Optimizing the vermicomposting of organic wastes amended with recyclable materials for production of nutrient-rich organic fertilizers: a review," Environmental Science and Pollution Research (25) No. 11, 2018.

[22] A. Chopde, et al., "Trash Can! An AI system for automatic classification of waste," in Proceedings of International Conference on Computational Intelligence and Sustainable Engineering Solution, 2022.

[23] J. Siswantoro, A.S. Prabuwono, & A. Abdullah (2014). Volume Measurement Algorithm for Food Product with Irregular Shape using Computer Vision based on Monte Carlo Method. Journal of Ict Research & Applications, 8(1).

[24] J. Siswantoro, et al. (2014). Monte Carlo method with heuristic adjustment for irregularly shaped food product volume measurement. The Scientific World Journal, 2014.

[25] J. Liu, et al. (2023). Cognitive cloud framework for waste dumping analysis using deep learning vision computing in healthy environment. Computers and Electrical Engineering, 110, 108814.

[26] I. N. Yulita, I. Wasito, and Mujiono, "GCLUPS: Graph clustering based on pairwise similarity," in 2013 International Conference of Information and Communication Technology, 2013.

[27] M. U. Fadhlullah, et al., "Sleep stages identification in patients with sleep disorder using k-means clustering," in Journal of Physics: Conference Series (2018).

[28] K. Afifah, I. N. Yulita, and I. Sarathan, "Sentiment Analysis on Telemedicine App Reviews using XGBoost Classifier," in 2021 International Conference on Artificial Intelligence and Big Data Analytics, 2021.

[29] X. Xu, et al., "SDD-CNN: Small data-driven convolution neural networks for subtle roller defect inspection," Applied Sciences (9), no. 7, 2019.

[30] Y. Peng and Y. Wang, "CNN and transformer framework for insect pest classification," Ecol Inform(72), 2022.

[31] D. Bhatt et al., "CNN variants for computer vision: History, architecture, application, challenges and future scope," Electronics (10) No. 20. 2021.

[32] H. J. Lee, et al., "Real-Time vehicle make and model recognition with the residual squeezenet architecture," Sensors (19) No. 5, 2019.

[33] X. Zhu, et al., "A multiple-blockage identification scheme for buried pipeline via acoustic signature model and SqueezeNet," Measurement (202), 2022.

[34] M. Rasool, et al. "A Novel Approach for Classifying Brain Tumours Combining a SqueezeNet Model with SVM and Fine-Tuning," Electronics (12) No. 1, 2023.

[35] H. Bai, "Design of Garbage Classification System Based on Artificial Intelligence Technology," in ACM International Conference Proceeding Series, Association for Computing Machinery, Dec. 2021, pp. 167–170.

[36] T. Ghanshala, V. Tripathi, and B. Pant, "A Machine Learning Based Framework for Intelligent High Density Garbage Area Classification," in Advances in Intelligent Systems and Computing, Springer Science and Business Media Deutschland, 2021, pp. 147–152

[37] W. Weifeng, et al., "Garbage image recognition and classification based on hog feature and SVM-Boosting," in Journal of Physics: Conference Series, IOP Publishing Ltd, Jul. 2021.

[38] P. Zhang, Y. Jia, and Y. Shang, "Research and application of XGBoost in imbalanced data," Int J Distrib Sens Netw(18) No. 6, 2022.

[39] X. Li et al., "Probabilistic solar irradiance forecasting based on XGBoost," Energy Reports(8), 2022.

[40] C. Wang, C. Deng, and S. Wang, "Imbalance-XGBoost: leveraging weighted and focal losses for binary label-imbalanced classification with XGBoost," Pattern Recognit Letter(136), 2020.

[41] D. Chicco and G. Jurman, "The advantages of the Matthews correlation coefficient (MCC) over F1 score and accuracy in binary classification evaluation," BMC Genomics (21) No. 1, 2020.

[42] S. Arlot and A. Celisse, "A survey of cross-validation procedures for model selection," Stat Survey (4), 2010.

[43] S. Arlot and M. Lerasle, "Choice of v for V-fold cross-validation in least-squares density estimation," Journal of Machine Learning Research (17), 2016.

# An IoT-based Smart Plug Energy Monitoring System

Lamya Albraheem*, Haifa Alajlan, Najoud aljenedal, Lenah Abo Alkhair, Sarab Bin Gwead

Department of Information Technology, College of Computer and Information Science,
King Saud University, KSU, Riyadh, Saudi Arabia

*Abstract*—Over the years, considerable efforts have been made to maintain electricity. However, there is still a significant need to explore new technologies and solutions conserve and enhance electricity supply. This project discusses research studies and applications conducted in the field of energy control, including a comparison of these applications undertaken in order to highlight constraints that need to be further addressed. This can be considered as the first step in developing a system that helps building owners to control their electricity consumption using Internet of Things (IoT) technologies. The main phases of the proposed system are data collection, data analysis and mobile application development. The project utilizes Wi-Fi smart plugs to collect active power consumption data, of which analysis is conducted on the cloud. The mobile application allows the building owner to manage buildings, and to obtain active and accumulated consumption data of plugged-in devices. This paper involves the architecture design of the proposed system, and the experimentation, testing, and implementation. The application was tested and the active and accumulative consumption per device and per building were reported. To confirm the accuracy of the active power consumption measurements from the smart plugs, a comparison is performed between these values and the active power consumptions measured by the company and shown on the labels. The results showed that using IoT-based smart plugs gives accurate readings.

*Keywords—Internet of things; IoT; smart plugs; electricity; energy consumption*

## I. INTRODUCTION

Electricity plays an important role in different aspects of our lives ranging from homes, industries, education, business, health, and transport [1]. The production of electricity may utilize a range of different resources, including non-renewable natural resources such as fossil fuels, in addition to renewable energy resources (RES) such as solar and wind. The burning of fossil fuels to produce electricity can cause various types of environmental damage, such as depletion of resources, increased pollution and waste generation [2][3]. Consequently, electricity consumption is becoming a major public concern and many countries and scientific communities are dedicating their effort to the search for solutions to control and manage the use of electricity [4].

In Saudi Arabia, efforts to conserve electricity have been intensified. According to the 2030 vision, the plan is to reduce energy consumption in different sectors by 20%, which will contribute significantly, saving about one million barrels of oil per day [5], [6]. Accordingly, the Saudi Energy Efficiency Center (SEEC) was established with the aim of conserving natural resources and enhancing energy efficiency. In addition, SEEC developed the Saudi Energy Efficiency Program (SEEP) which implemented a number of campaigns, including 35

initiatives to increase energy efficiency and improve society's awareness. SEEP also established the National Energy Services Company (Tarshid) to achieve two main objectives which are: the rehabilitation of government buildings to reduce consumption and support for the private sector with investment in the energy efficiency services sectors [7]-[9]. Therefore, to contribute to these initiatives, innovative ideas are needed which support and enhance recent technologies in order to monitor the electricity consumption of buildings.

The existing solutions can be classified according to meters' types into traditional meters and smart meters. For the traditional meter, manual consumption readings need to be conducted by humans for each building. Smart meters, on the other hand, can store the data themselves and send it automatically to the electricity company [10]. However these meters are only capable of recording the electricity consumption of the building as a whole; they are not capable of providing more detailed information, for example the consumption of each individual appliance. Richer information of this type could potentially support building rehabilitation projects by identifying those appliances consuming most power, providing a case for replacing them with more energy-saving ones. More detailed consumption information could also enhance the consumption awareness of building owners, supporting them in understanding electricity usage patterns.

To address the above-mentioned problems, a new technology is needed, capable of collecting and measuring building electricity consumption to inform understanding of usage behaviors. The IoT, in conjunction with smart plugs, can collect electricity consumption information in respect of plugged-in devices, supporting enhanced user awareness and helping to identify those devices that consume the most electricity [11]. This project will therefore develop a mobile application using the IoT and smart plugs to enable the building owners to access their electricity consumption data. The application will also allow building owners to understand the electricity consumption of appliances, which may assist in cost reductions.

The contributions from this study are the following:

- A review and comparison of different applications that have been developed for electricity monitoring systems highlighting any limitations and areas for improvement.

- Development of an IoT-based smart plug energy monitoring system utilizing smart plug devices and the cloud service for data analysis. The data collected and stored on the cloud can be further deployed within an artificial intelligence model, to detect consumption patterns and identify anomalies.

- An experimental, real-world case study to test the functionality of the proposed system and report the results.

The remainder of this paper is organized as follows: Section II presents the background information necessary for the understanding of the project; in Section III, related studies of similar applications are reviewed and compared with the presented application; Sections IV and V provide a description of the proposed solution, together with the hardware and software specifications; Section VI describes and discusses the experiment based on a real-world case study and reports the results; finally, Section VII provides the conclusion and recommendations for future work.

## II. BACKGROUND

### A. Electricity Consumption

A range of different concepts, measurements and equations is necessary to the understanding of electricity consumption, as well as an appreciation of the distinction between power (Watts/kW) and energy (Watthour/kwh). Firstly, electricity can be defined as the main source of energy that provides a flow of electrical power. It is measured in Watts (W), which is the unit of electrical power. The power is calculated by multiplying the current (Ampere A) and the voltage (V) as shown in Eq. (1) [12][13]:

$$Power\ P\ (Watts)\ =\ Current\ (A)\ *\ Voltage\ (V)\ \ (1)$$

Power is the electricity currently being used, which is also referred to as active power consumption [13]. Energy can be defined as the total amount of electricity consumed over a period of time (i.e. accumulative power consumption) and is computed according to Eq. (2) [13][14]:

$$Energy\ (Wh)\ =\ Power\ (W)\ *\ hours\ (h)\ \ \ (2)$$

$$Energy\ (kWh)\ =\ Energy\ (Wh)/\ 1000\ \ \ \ (3)$$

For example, if you use a device that gives active power equal to 500 Watt (0.5 kW) for five hours, then the energy or the total amount of electricity that has been consumed is 2,500 Wh or 2.5kWh. To sum up, in order to compute the electricity consumption of any device, the active power consumption (W) and the number of daily working hours of the device (h) must be known. Then the daily and monthly electricity consumption can be calculated as follows [14]:

$$Daily\ Electricity\ consumption\ of\ the\ device\ =$$
$$Power\ (watt)\ *\ Daily\ working\ hours\ \ \ \ \ \ (4)$$

$$Monthly\ Electricity\ consumption\ of\ the\ device\ =$$
$$Daily\ Electricity\ consumption\ *\ 30\ \ \ \ \ \ (5)$$

### B. Smart Plugs

The smart plug is defined as 'a separate electronic piece of hardware that serves as a proxy between the energy source and energy-consuming device'. So, it is an electronic device that allows the user to obtain real-time data of electricity consumption of the electric appliance or device, which is plugged in using a web panel or mobile application. The plugs also convert the appliances into smart devices to control them remotely [15], [16].

The hardware components of the smart plug, can be described as consisting of four sub-systems units which are: power meter; power switch; network node; and processing. The power meter is responsible for collecting the active energy consumption of the appliances connected to the smart plugs. Different information can be measured including active power consumption W, voltage V and current A. The power switch can be used to control the devices connected to the plugs by turning them to on or off, using the application. The network node allows a connection to be made with different external devices such as gateways using wireless technology, for example Wi-Fi, or Bluetooth low energy. The primary core components of the plug are the processing unit, which arranges the interaction between the power meter and the network unit [17].

Regarding commercial smart plugs products, a number of different companies provide plugs with a range of features. The consumer wishing to select the most appropriate product for their needs will need to understand their requirements. Table I presents brief information regarding the features of some examples of the commercial smart plugs that are available.

According to Table I, electricity consumption data may be transmitting utilizing different wireless technologies such as Wi-Fi, BLE, Zigbee. It is evident that the majority of the products use Wi-Fi, while Mokosmart products provide different wireless configurations. Regarding the transmission range, the coverage range will equate to that of the Wi-Fi router to which the plug is connected. If, as in the case of Mokosmart, BLE is used, the range will be 100 meters to connect with the mobile application or gateway. Regarding the maximum power of the connected devices, all plugs can be connected with devices that have a maximum power of 1800 W, while Mokosmart can be connected with 2400 W. For the power consumption of the plug itself, it can be seen that Eve and Mokosmart provide the lowest power with 0.001 and 0.075 respectively. Regarding pricing, D-Link and Mokosmart are the cheapest products.

Regarding the features, it can be seen that smart plug products provide one or both of two main functions: remote controlling and monitoring electricity consumption. The remote controlling allows the switching on and off of electronic devices using the mobile phone application or a hands-free voice control. The electricity consumption monitoring function allows power consumption of any plugged-in device to be monitored, using a mobile application or a web panel. Consumers need to exercise caution when selecting a product, as may items provide remote controlling only, for example D-Link. In addition, a critical feature to be considered by consumers who interested in developing the application is the provision of a software development kit (SDK) and the compatibility of the smart plug with IoT cloud services.

TABLE I.    SMART PLUG PRODUCTS

| Company | Transmission Technology | Transmission range | Maximum power (W) | Power consumption of the plug (W) | Price (SR) | Features |
|---|---|---|---|---|---|---|
| Mokosmart[28] | Bluetooth ,Wi-Fi, Zigbee | Above 100 meters for the BLE. Internet-connected in the Wi-fi | 2400 | 0.075 | 75 | • Monitoring energy consumption.<br>• Remote controlling.<br>• Support API for APP and cloud server development.<br>• Measures active and accumulative power consumption.<br>• Support SDK. |
| Eve [29] | Wi-Fi | Internet-connected. | 1800 | 0.001 | 263 | • Monitoring energy consumption.<br>• Remote controlling.<br>• Schedule devices. |
| TP-Link [30] | Wi-Fi | Internet-connected. | 1800 | 3.50 | 131 – 188. | • Monitoring energy consumption.<br>• Remote controlling.<br>• Amazon Echo Voice Control.<br>• Schedule devices. |
| WeMo(Belkin) [31] | Wi-Fi | Internet-connected | 1800 | 1.5 | 188 – 375 | • Monitoring energy consumption.<br>• Remote controlling.<br>• Hands-free voice control.<br>• Schedule devices |
| Insteon [32] | Insteon | Everywhere | 1800 | < 0.4 | 487 | • Monitoring energy consumption.<br>• Remote controlling.<br>• Schedule devices. |
| D-Link[33] | Wi-Fi | Internet-connected. | 1800 | < 3 | 59 | • Remote controlling.<br>• Hands-free voice control.<br>• Schedule devices. |

The SDK allows the user to interact with the plugs in the implementation phase. In case the user wishes to utilize IoT cloud services, the plugs should be compatible with cloud platforms using well-known IoT protocols such as MQTT (Message Queuing Telemetry Transport). In accordance with the conclusions from this discussion and in light of the available features, the smart plug to be used in this project is the Mokosmart. This provides different wireless configuration; can be connected with high power devices up to 2400 W; has the lowest power consumption; and is compatible with the IoT Cloud platform that supports MQTT. These plugs represent the sensors to be used in the project.

## III. RELATED WORKS

A number of research studies and applications conducted and developed in the field of energy monitoring systems are presented in this section. The significant work is reviewed, which contributed to the development of the energy monitoring systems including both multi-sensor and single-point sensor approaches. Moreover, the section considers the different applications developed for energy monitoring and presents a comparison between them, to reveal the limitations and any issues that require improvement.

### A. Research Studies

In this section, existing research studies in the field of appliance load monitoring are presented. These studies can be categorized into smart meter approaches or smart plugs approaches. This categorization is based on the location of the sensors used to collect electricity consumption data. For the smart meter approaches, the meter is placed at the entrance of the building and can measure the overall electricity consumption. The smart plugs, on the other hand, are located into each socket to measure the electricity consumption for each device [18]. These studies can be also categorized into multi-sensor or single-point sensor projects, according to the number of sensors used to collect the electricity consumption

data. In the multi-sensor approaches, the sensors should be installed at the power outlets or at each device, while, in case of single-point approaches, there is only one sensor to monitor the building [19]. All of these approaches aim to monitor the electricity consumption of appliances used in a building.

*1) Single-point sensor approaches:* The smart meter can collect the overall electricity consumption of any building; however, it does not provide any appliance-specific (that is, device-level) consumption information. Therefore, in order to recognize the appliances according to their electricity consumption, there is a single sensor attached to the smart meter to collect different characteristics of electrical load. Machine learning techniques are then applied to recognize different appliances. Each of these approaches involves its own issues; for example, in the case of the smart meter, a technical expert is required to undertake the setup of the smart meter in accordance with requirements; the results may be inaccurate; and previous knowledge of appliance power signatures is required in order to implement the machine learning techniques as these require a training phase [18], [19].

*2) Multi-sensor approaches:* Artur et al. proposed a study of an IoT-based solution to identify household appliances, monitor their consumption and detect anomalies in these devices. The identification of these appliances is possible where they possess a unique Electric Load Signature (ELS). The ELS can be defined as an electrical characteristics unique to each appliance which includes: voltage, current, active, reactive and powers. The proposed solution is a Home Energy Management (HEM) system capable of exposing and identifying appliances, and measuring their electricity consumption. The smart plugs are used to read the electrical parameters of each appliance, and the data is sent to HEM using the internet (Wi-Fi) or ZigBee. The ELS thus created is then stored in a database. The data is subsequently analyzed using a machine-learning algorithm to detect the appliance. The results demonstrate that 10,799 records were collected and that the system perform the required training and analysis to classify these records and identify the appliances. The records created included 3,600 records for the refrigerator, 3,599 records for the washing machine and 3,600 records for the TV [2].

In 2019, Ashwin and Krishnamoorthy proposed an IoT-based smart plug load energy management system for an office environment. The main objectives of the study were to improve energy management, and to controlling devices. The project used smart plugs to measure the total consumption of each appliances in the office. The appliances used to test the system included a printer and a coffee vending machine. The developed system is a web application to monitor the smart plugs, collect data and send notifications to the users where a pre-determined limit is exceeded. The system also implemented a scheduling method in which the devices could be turned off at a specific time. Moreover, the system could identify consumer behavior. An analysis performed to compare the total energy consumed before and after implementing the system demonstrated a reduction in electricity consumption [20].

Ahmed et al. propose a method that aims to monitor electric power using smart plugs. It targets analyzing and understanding of the energy consumed by appliances. A mobile application has been developed on a Windows phone to control appliances in a room by an on-and-off switch and the establishment of operating schedules. The application also provides features to design the layout of the user's house in addition to the behavior of connected devices. On the other hand, an interactive web application has been designed to show the energy consumed by different houses on the map, to help the Power Distribution Companies to analyze and study consumption behavior. The results of this study contributed to increased awareness of energy conservation in UAE and to reductions in consumption [1].

In 2020, Shohin Aheleroffa et al. proposed an IoT-enabled framework that aims to transform any appliance into a smart appliance and to allow the collection of data using sensors and actuators. As a case study, researchers integrated an IoT board within the central control board of a traditional refrigerator to transform it into a smart refrigerator. This board can collect data which includes: temperature and cooling level, and which also reads the states of different actuators such as the heater, the compressor, or the air fan. The data collected is periodically sent to the IoT platform using Wi-Fi technology to store data in a database called Ubidots. This study in [21] also lists suggestions for different IoT platforms which could be utlilized in similar systems such as: AWS IoT, IBMWatson IoT, and Azure IoT. The IoT platform can support the analysis and visualization of the received and can display the results on the dashboard. The user can also control their refrigerator using a mobile phone connected to the device by Bluetooth technology. It should be noted that this proposed framework can be applied in respect of all home appliances[21].

According to the studies outlined above, it is clear that different approaches exist which may be categorized into single-point-based approaches or multi-sensor-based approaches. The single-point sensors can provide data about overall consumption and anticipated consumption per device based on machine-learning algorithms. However, they do require technical expertise to achieve the correct setup in attaching the sensor to the smart meter as well as a priori knowledge of appliance power signatures. On the other hand, multi-sensor-based approaches can provide device-level electricity consumption information, but requires a separate smart plug for each individual device.

*B. Applications*

In this section, a number of applications in the field of electricity monitoring are presented, and their features outlined. A comparison is also provided between these applications and the proposed application, so that the best features of similar applications may be incorporated and to identify limitations and areas for improvement.

*1) SmartLife application:* SmartLife is a smart device management application which is used to control smart devices such as smart plugs, smart cameras, or smart vacuum

cleaners. It is compatible with multiple smart plugs such TECKIN Smart Plug, Tan Tan Smart Plug and YTE Smart Plug and with multiple smart devices [22]. SmartLife Application measures electrical consumption of the smart devices only where they include an energy monitoring feature. Bluetooth low energy technology connects the application to the smart plugs. The application provides building owners with features such as the ability to add and control multiple devices, and to receive notifications when scheduled events occur. Additionally, it provides a monthly report including statistics of electrical consumption, a timer or scheduling tool for automatic control of devices, and cloud storage using an Amazon server. Furthermore, it provides a family control facility to allow differential control permissions to different family members — for example limiting the ability to control settings to a single family member while allowing all to control the devices. [23]

*2) Insteon hub application:* The Insteon system consists of a web and smartphone application which converts the home into a smart home. This facilitates the control of home appliances. Insteon requires a hub to exert control over compatible devices. The hub is plugged into the wall and connected to router via Ethernet [24]. There is no limit to the number of devices that may be added on Insteon hub which Insteon connects to the router using the home's existing power wires. This helps Insteon signals to transfer commands in the house unaffected by walls or other Wi-Fi blocking materials. To prevent signal overload [25], the radio frequency used by Insteon for communication is distinct from the one used by Wi-Fi. The Insteon app enables the building owners to manage smart plugs by adding devices, and by adding rooms that can group devices according to their position, and defining zones that can group rooms within the same building. In addition, it permits the user to establish schedules for controlling devices, receives notification relating to its sensor, and can flag up warnings relating to water leaks, motion, and door/window breaches if the necessary sensors are in place. [26].

*3) Zuli application:* The mission of Zuli application is to track and manage the building's appliances. This is a smartphone application compatible with a Zuli smart plug. Communication with the smart plug through Bluetooth is necessary for use of the features of the application [27]. The Zuli application contains numerous features, for instance supporting interaction between devices able based on the owner's location, through the utilization of iBeacon technology using Bluetooth low energy. The application can monitor energy usage and obtain the number of Watts, Volts, and Amps that proceed through the plug. It can additionally obtain the anticipated monthly costs, can assign a schedule for every day on the week and assign a timer to automatically turn on and off the devices [28].

*4) Sense application:* Sense is a web and smartphone application for monitoring electricity consumption. It requires hardware called the Sense monitor to be installed in the electrical panel of the building. Two sensors, clamp around

the main power leads to ascertain the amount of electricity being used [29]. Sense uses a machine learning algorithm to automatically classify the active devices based on historical data of similar devices collected from other users. The device name may then be confirmed or modified by the consumer [30].To run the Sense application, the application should be connected to the Sense monitor via Wi-Fi technology [29]. The Sense monitor collects energy usage data and sends it through Wi-Fi to the cloud. Consumers may thento track thir electricity consumption using either their smartphone or computer. Sense helps consumers to reduce electricity utilization by encouraging them to set targets and track progress. It also allows them to monitor their electrical consumption in real time. Additionally, it provides daily, weekly, and monthly reports which include energy consumption measurements, average usage, and statistics related to specific devices [31]. In addition, the Sense application can detect the value of the monthly bill. Furthermore, Compatible with Wemo and Kasa smart plugs, it is therefore capable of utilizing the multi-sensor approaches represented by the smart plugs to identify devices faster, to compute consumption per device more accurately and to allow consumers to control their devices directly [32].

*5) EnergyCloud application:* EnergyCloud is a mobile application that uses machine learning technology to analyze usage patterns. It aims to reduce electricity consumption and costs through the ready availability of energy data [33]. The requirements of this application include: the EnergyCloud Sensor which is installed within the electricity meter to transmit meter readings to a gateway called CloudConnector. This gateway sends all the electrical consumption data to the cloud [34]. The EnergyCloud Sensor is compatible with analog disk meters and digital meter [35]. The mobile application provides many services which include real-time consumption measurement and make a monthly consumption comparisons. The application also provides tools to encourage reductions in consumption, such as notifications where usage has been successful decreased, or where a predefined consumption limit has been exceeded [36]

Table II shows the availability of a range of different types of applications, for example: single-point sensor applications such as EnergyCloud and multi-sensor based applications such as SmartLife, Insteon, and Zuli. One application, Sense, is capable of operating using both approaches. The EnergyCloud application requires installation of a sensor within the electrical meter to collect the overall energy consumption data. It uses a machine-learning algorithm to identify devices and provides anticipated readings of device-level consumption. However, as discussed in the literature review section, above, there are problems attendant upon the single-point approach, such as the production of inaccurate results, more complex sensor installation requirements necessitating the services of an electrician,, and the need for previous knowledge of the consumption profiles of the devices [18], [19]. In the case of multi-sensor based applications, it can be seen that smart plugs play an essential role, and are utilized for different objectives:

they allow remote controlling of the devices without energy monitoring or may provide energy monitoring in addition to the remote controlling features. Insteon is an example of an application solely providing remote control functionality for devices, though it is important in terms of the objective of this paper to maintain the focus on applications which deliver energy monitoring functionality, such as Zuli. It may also be seen in Table II that none of the applications currently available supports the Arabic language—a gap in the energy monitoring market that urgently needs to be filled. In addition, the majority of available applications do not support the 'manage building' feature which provides the capability for managing multiple buildings. Smartlife is the only application to benefit from this feature. In terms of a notifications facility to support users in reducing energy consumption, this is available in only one application, EnergyCloud. Applications providing effective monitoring consumption typically support smart plug management, appliance management, provision of historical as well as active power data, and cloud storage utilization. Consequently, the user is recommended to review products carefully before selecting, to ensure they incorporate these essential capabilities.

TABLE II.    COMPARISONS BETWEEN APPLICATIONS

| Features | SmartLife | Insteon | Zuli | Sense | EnergyCloud | SPEM |
|---|---|---|---|---|---|---|
| Manage Smart Plug | □ | □ | □ | □ | X | □ |
| Manage building | □ | X | X | X | X | □ |
| Manage Appliance | □ | □ | □ | □ | X | □ |
| Monthly cost of devices | □ | X | □ | □ | □ | □ |
| Expected cost of the building consumption | x | X | X | □ | □ | □ |
| Monthly Report | □ | X | □ | □ | □ | □ |
| Historical Power | □ | X | □ | □ | □ | □ |
| Provide consumption alert | X | X | X | X | □ | □ |
| Arabic Language | X | X | X | X | X | □ |
| Turn off/on devices | □ | □ | □ | □ | X | X |
| Control Voltage | □ | □ | X | □ | X | X |
| Voice control | □ | □ | X | X | □ | X |
| Provide Cloud Storage | □ | X | X | □ | □ | □ |
| Multi sensor/ Single sensor | Multi sensor | Multi sensor | Multi sensor | Multi sensor/ Single sensor | Single sensor | Multi sensor |

We will develop an IoT- based smart plugs system which is informed by the domain analysis presented in this section and which assists owners to monitor the electricity consumption of their buildings. The system will allow building owners to register their details within the application, to use the application features, will support Arabic language and provide multiple features including smart plug management, appliance management, active and historical consumption data per appliance, monthly reports covering consumption and anticipated costs. Additionally, a 'manage building' capability will be included as well as alerts to support reductions in consumption.. Further development may be undertaken in future to develop features relating to the on/off control of the smart plugs and the use of voice control.

## IV.    PROPOSED SOLUTION

### A. System Architecture

This study proposes a solution consisting of an IoT smart electricity monitoring system which assists building owners to monitor electricity consumption. The main components of the solution are: smart plugs, server, and mobile application. The application will operate as presented in Fig. 1. Smart plugs will be installed and configured in the buildings which, once connected to the building will, using Bluetooth Low Energy (BLE), transmit information to a gateway, including: smart plug ID; active power consumption (watt); real-time current (A); and voltage (V). The gateways will collect the information and send them to the server. Once active power consumption data collection becomes operational, a processing and analysis task must then be undertaken to calculate the accumulative electricity consumption of the appliances connected to the plugs. The mobile application enables building owners to manage smart plugs and appliances, to monitor the active and accumulative consumption of the appliances, and to identity those appliances consuming the most electricity. The proposed solution will thus contribute to enhancing user awareness, encouraging the replacement of older devices, and better energy conservation, thus reducing electricity bills and achieving the sustainability objectives.

The architectural design of the proposed system has four layers as shown in Fig. 2: the perception layer, the network layer, the data storage layer, and the application layer. The perception layer is the first layer of the IoT architecture, in this which the smart plugs are used to detect and collect information including smart plug ID, active power consumption (watt), real-time current (A), and voltage (V). The second, or network layer connects the smartplugs and the network equipment (that is, the gateway), to transfer

information to the servers. The data storage layer is represented by the IoT platform that can receive information from the sensors and store it in a cloud-based database. The application layer allows user interaction with the system, using the mobile application, and is responsible for the provision of application-specific services to the user.
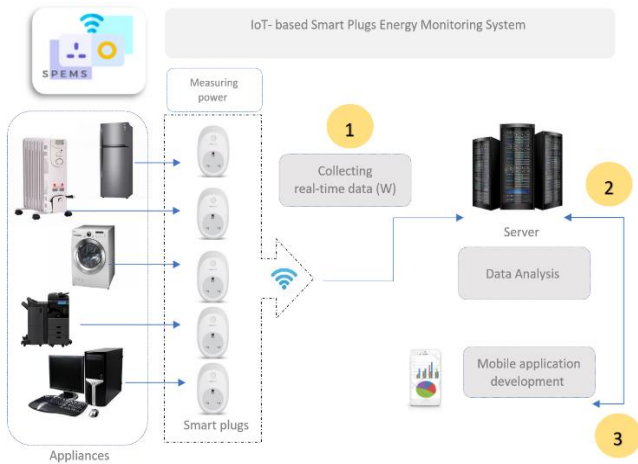


Fig. 1.   The proposed solution.
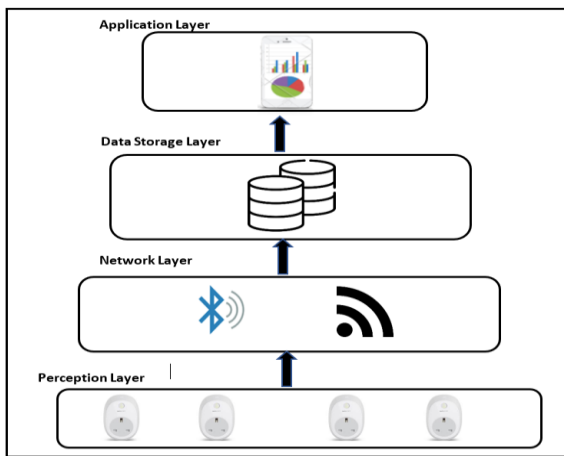


Fig. 2.   The IoT architecture of the proposed solution.

## V.   SYSTEM IMPLEMENTATION

The main goal of the proposed system is the collection of active power consumption data for any device and the computation of the energy consumption. The Wi-Fi smart plug is utilized as a hardware component. In accordance with the findings of the comparative enquiry, presented in Table I, the smart plugs selected for this project are Mokosmart. These plugs provide a range of potential wireless configurations, which are Wi-Fi, BLE and Zigbee. BLE smart plugs must be connected first with gateway and then with the Wi-Fi modem, while the Wi-Fi plugs are connected directly to the modem. This project used the Wi-Fi plugs, as the most cost-effective choice, we used the Wi-Fi plugs.The Mokosmart Wi-Fi plugs can be connected with high power devices up to 2400 W, have low power consumption, and are compatible with the IoT Cloud platform that support the Message Queuing Telemetry Transport (MQTT) protocol. These plugs represent the sensors that will be used in the proposed project. Samsung phones were

for this project, since the application is designed to be compatible with Android platform.

In terms of the software, a range of different tools are used to develop the proposed system which includes three main processes: data collection, data analysis and mobile application development. For data collection, the Amazon Elastic Compute Cloud (Amazon EC2) is used, which is a cloud service provided by Amazon which provides cloud computation [37]. It is compatible with the MQTT protocol, so it is used as server to receive records from smart plugs. The MQTT protocol, a publish/subscribe protocol for messaging transport with minimal network bandwidth, is a standard messaging protocol that serves IoT devices. The smart plugs used in the project support the MQTT protocol, once they are connected to the internet. They will publish power data to MQTT Broker and the MQTT Client will subscribe to the topic to get the power data [38].

Subsequently, a python script was developed from scratch, as shown in Fig. 3, to read data from smart plugs using the MQTT protocol and to store it in the database. The python code is written using Jupyter Notebook [39] which provides an online python environment. A python code was also written to analyze received data and to compute daily, monthly consumption of each device, and also the daily, monthly consumption of each building, in addition to the anticipated cost of electricity consumption per month.  For the database, the Firebase was utilized, a platform provided by Google with many services for developed mobile and web applications [40]. It is used to store user information and data received from the smart plug.  The mobile application was developed using Android Studio 2020.3.1 [41].



```python
def start_plug():
    try:          # try to connect to AWS EC2 with provided ip and port
        client = mqtt.Client("digit_mqtt_test")
        client.on_connect = on_connect
        client.on_message = on_message
        client.connect('3.142.240.110', 1883)
        client.loop_forever()     # loop forever while true
    except Exception as e:
        print(e)
```

Fig. 3.   Code segment of connect to MQTT protocol.

The steps followed to connect the system components are set out below:

*1) Configuring* the smart plugs to connect them to the EC2 cloud service;

*2) Implementing* the python code to read data from the smart plugs using the MQTT protocol as presented in Fig. 3;

*3) Connecting* EC2 to the database to store the data;

*4) Connecting* the mobile application to the database.

## VI.   THE EXPERIMENT

The IoT-based smart electricity monitoring system is developed as a mobile application that use the Internet of Things (IoT) and Smart Plugs to enable building owners to access their electricity consumption data and to understand the electricity consumption of individual devices connected to the plugs which can contribute to reducing electricity bills. This experiment was conducted in residential buildings. The experiment consists of three phases:

- Installation phase: The actual installation of the smart plugs in the building and connecting them to devices.

- The execution phase: The demonstration of the use of the proposed application to monitor real-time data and compute daily and monthly electricity consumption.

- Testing phase: To conduct performance and stress testing.

### A. Installation and Deployment Phase

In terms of the hardware used, a number of home appliances were tested in this experiment including refrigerator, hair dryer, television and washing machine). These devices are attached to Wi-Fi smart plugs according to the specification presented in Table III.

TABLE III. SPECIFICATIONS OF HOME APPLIANCES

| Device | Consumption range measured by company (W) that exist on the label | Model no | Company |
|---|---|---|---|
| Refrigerator | 400 - 550 | ASKN – SBS - 521-RFG | ASKEMO |
| Hair dryer | 1000 - 1200 | EW - 920 | Easy Way |
| Television | 120 - 155 | 65UJ670V - TD | LG |
| Washing machine | 2000 - 3000 | WF21T6500GV | Samsung |

### B. Execution Phase

In the execution phase, various home appliances are monitored. The system will start to receive the sensor readings from home appliances and to perform different functions including the following:

*1) Active power consumption per device:* The proposed system lists all the connected home appliances with their active power consumption measured using Watt (W). As shown in Table IV and Fig. 4, different readings are taken for each device. This gives building owners an indication which are the devices that have high consumption. It can be seen that the hair dryer and washing machine have higher active consumption that the refrigerator and the television.
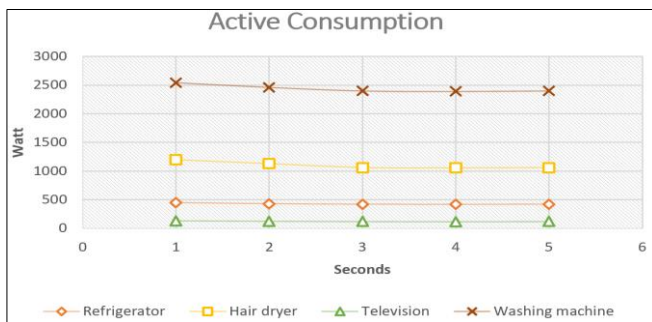


Fig. 4. Active power consumption for different appliances.

It is important to make sure that all electrical appliances are efficient in consuming energy. Consumers can know the efficiency of any appliance by referring to the attached energy efficiency label. Accordingly, the proposed system should transmit an efficiency alert to building owner if a device exceeds the standard consumption or has a normal consumption. The standard consumptions are typically defined by the electricity company to increase consumer awareness. To confirm the accuracy of the active power consumption measurements from the smart plugs, a comparison is performed between these values and the active power consumptions measured by the company and shown on the labels. The results are shown in Table V and Fig. 5.

TABLE IV. ACTIVE POWER CONSUMPTION PER DEVICE (W)

| Device | Reading 1 | Reading 2 | Reading 3 | Reading 4 | Reading 5 |
|---|---|---|---|---|---|
| Refrigerator | 450 | 430 | 420 | 417 | 420 |
| Hair dryer | 1200 | 1130 | 1060 | 1055 | 1060 |
| Television | 130 | 125 | 120 | 118 | 120 |
| Washing machine | 2540 | 2460 | 2400 | 2391 | 2400 |
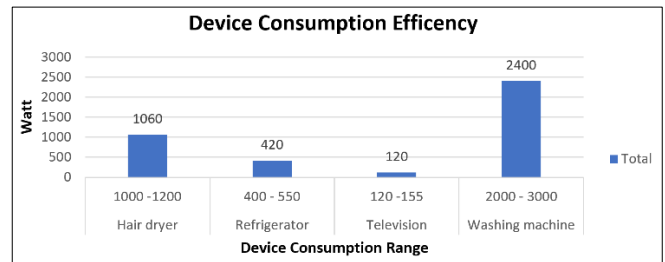


Fig. 5. The device consumption efficiency.

TABLE V. COMPARISON BETWEEN THE MEASURED AND ACTUAL ACTIVE CONSUMPTION

| Device | Consumption measured by smart plug (W) (average of the actual active consumption ) | Consumption range measured by company (W) (that exist on the label) |
|---|---|---|
| Refrigerator | 420 | 400–550 |
| Hair dryer | 1060 | 1000-1200 |
| Television | 120 | 120–155 |
| Washing machine | 2400 | 2000-3000 |

*2) Accumulative power consumption per device:* As mentioned previously, in order to compute much the electricity consumption of any device, there is a need to know the active power consumption (W) and the number of daily working hours of the device (h). Then the daily and monthly electricity consumption can be calculated, as shown in Table VI and Fig. 6. The active power of the refrigerator is 420 Watt for 24 hours, so the energy or the total amount of electricity consumed is 10800Wh or 10.8kWh. The monthly consumption can calculated according to the number of days the device is used. Additionally, the building owner shall be able to display a monthly report of device consumption of a

building and the expected monthly cost of the electricity consumption, based on the electricity company tariff.
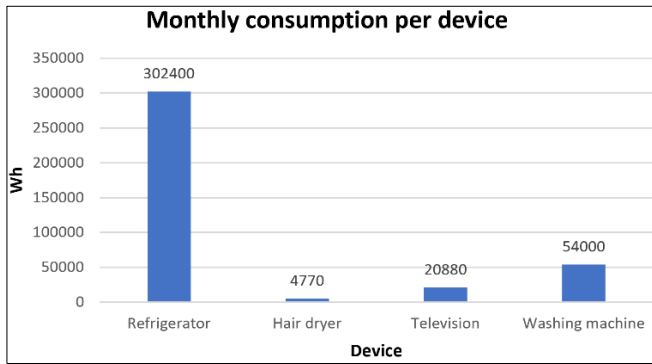


Fig. 6.    The monthly consumption per device.

TABLE VI.    DAILY ELECTRICITY CONSUMPTION PER DEVICE

| Device | active power consumption (W) | # of hours the device is used (h/day) | Daily consumption (Wh) | monthly consumption (Wh) |
|---|---|---|---|---|
| Refrigerator | 420 | 24 | 10080 | 302400 |
| Hair dryer | 1060 | 0.15 | 159 | 4770 |
| Television | 120 | 5.8 | 696 | 20880 |
| Washing machine | 2400 | 0.75 | 1800 | 54000 |

*C. Testing Phase*

*1) Performance testing:* Performance testing is a type of software testing that is used to analyze a system's capabilities and performance under a certain workload. To test our application's performance, we used activity monitor software which tracks operation. As shown in Fig. 7, the test results over a 30-minute period demonstrate that the CPU usage of the program was 1% of the total available CPU as a minimum value, though the CPU usage may potentially reach 32 % as a maximum value in specific situations.
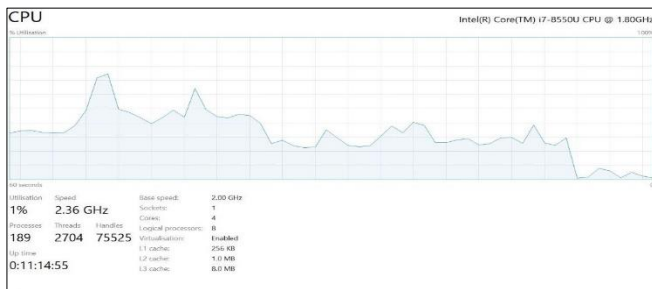


Fig. 7.    Minmum and maximum CPU performance.

With regard to memory usage, during a 30-minute testing period, it was observed that the proposed application allocates around 395MB of the total available memory.

*2) Stress testing:* Stress tests are used to test a system's capacity beyond its top limit, which can cause performance degradation. To perform the stress testing we used monkey which is a command-line utility that provides the system with a pseudo-random stream of user events. The command, (adb shell monkey-pcom.example.log_in 10000 > testfinal.txt ) was utilized to run stress testing in the proposed system. The number of user events was 1000. The system is capable of handling 7340 random user actions, such as clicks, touches, and addition of a device, as shown in Fig. 8. The test completed 7340 occurences, demonstrating that the system has no unhandled exceptions and will work successfully under the stress of unexpected activities.



Fig. 8.    Stress testing.

## VII.    CONCLUSION

IoT has a huge benefit to consumers in terms of energy efficiency. The proposed system which is an IoT-based Smart Plugs electricity monitoring system allows consumers to measure, analyze and check energy active and accumulative consumption per devices and per building. This can help consumers to make rapid adaptations and corrective actions to control their energy consumption and costs. The system also can be useful for individuals to increase awareness, to know their electricity consumption and to replace high energy consuming devices. Furthermore, the system can support rehabilitation projects, identifying devices that need to be replaced.

For future work, the collected data can be used in an AI model to detect anomalies and use machine learning techniques to predict patterns of future consumption to recognize the devices connecting automatically to smart plugs. The system also can provide suggested corrective actions that will lead to improvements in energy efficiency.

REFERENCES

[1]  S. Musleh, M. Debouza, and M. Farook, 'Design and implementation of smart plug: An Internet of Things (IoT) approach', in 2017 International Conference on Electrical and Computing Technologies and Applications (ICECTA), Nov. 2017, pp. 1–4. doi: 10.1109/ICECTA.2017.8252033.

[2]  A. F. da S. Veloso, R. G. de Oliveira, A. A. Rodrigues, R. A. L. Rabelo, and J. J. P. C. Rodrigues, 'Cognitive Smart Plugs for Signature Identification of Residential Home Appliance Load using Machine Learning: From Theory to Practice', in 2019 IEEE International Conference on Communications Workshops (ICC Workshops), May 2019, pp. 1–6. doi: 10.1109/ICCW.2019.8756885.

[3]  'Saudi Electricity Company'. https://www.se.com.sa/en-us/Pages/OurActivitiesTowardsCommunity3.aspx (accessed Sep. 05, 2022).

[4]  'قطاع المباني'. http://www.seec.gov.sa/ar/energy-sectors/buildings-sector/ (accessed Sep. 05, 2022).

[5] 'Targeted Sectors'. http://www.moenergy.gov.sa/en/OurPrograms/SPFEE/Pages/TargtedSec tors.aspx (accessed Sep. 05, 2022).

[6] 'Buildings retrofit – National Energy Services Company (NESCO) | Tarshid'. https://www.tarshid.com.sa/our-services/buildings-retrofit/ (accessed Sep. 05, 2022).

[7] N. K. Suryadevara and G. R. Biswal, 'Smart Plugs: Paradigms and Applications in the Smart City-and-Smart Grid', Energies, vol. 12, no. 10, pp. 1–20, 2019.

[8] 'Yearly Statistics'. https://www.sama.gov.sa/en-us/economicreports/pages/yearlystatistics.aspx (accessed Sep. 05, 2022).

[9] N. Angelova, G. Kiryakova, and L. Yordanova, 'The great impact of internet of things on business', TJS, vol. 15, no. Suppl.1, pp. 406–412, 2017, doi: 10.15547/tjs.2017.s.01.068.

[10] W. Li, 'Internet of things (IoT) based adaptive energy management system for smart homes', Thesis, Newcastle University, 2019. Accessed: Sep. 05, 2022. [Online]. Available: http://theses.ncl.ac.uk/jspui/handle/10443/4633

[11] N. M. Kumar and P. K. Mallick, 'The Internet of Things: Insights into the building blocks, component interactions, and architecture layers', Procedia Computer Science, vol. 132, pp. 109–117, Jan. 2018, doi: 10.1016/j.procs.2018.05.170.

[12] 'Measuring electricity - U.S. Energy Information Administration (EIA)'. https://www.eia.gov/energyexplained/electricity/measuring-electricity.php (accessed Sep. 05, 2022).

[13] 'kW and kWh Explained – Understand & Convert Between Power and Energy'. https://www.energylens.com/articles/kw-and-kwh (accessed Sep. 05, 2022).

[14] K. A. Rahman, A. M. Leman, M. F. Mubin, M. Z. M. Yusof, A. Hariri, and M. N. M. Salleh, 'Energy Consumption Analysis Based on Energy Efficiency Approach: A Case of Suburban Area', MATEC Web of Conferences, vol. 87, 2016, Accessed: Sep. 05, 2022. [Online]. Available: https://cyberleninka.org/article/n/1488447

[15] L. Gomes, F. Sousa, and Z. Vale, 'An Intelligent Smart Plug with Shared Knowledge Capabilities', Sensors, vol. 18, no. 11, Art. no. 11, Nov. 2018, doi: 10.3390/s18113961.

[16] B. Karlin et al., 'Characterization and Potential of Home Energy Management (HEM) Technology', 2015, Accessed: Sep. 06, 2022. [Online]. Available: https://escholarship.org/uc/item/6qd1x5js

[17] G. Galioto, N. Galioto, C. Giaconia, L. Giarré, G. Neglia, and I. Tinnirello, 'Smart plugs: A low cost solution for programmable control of domestic loads', in 2014 AEIT Annual Conference - From Research to Industry: The Need for a More Effective Technology Transfer (AEIT), Sep. 2014, pp. 1–6. doi: 10.1109/AEIT.2014.7002015.

[18] D. Zufferey, C. Gisler, O. A. Khaled, and J. Hennebert, 'Machine learning approaches for electric appliance classification', in 2012 11th International Conference on Information Science, Signal Processing and their Applications (ISSPA), Jul. 2012, pp. 740–745. doi: 10.1109/ISSPA.2012.6310651.

[19] M. Weiss, A. Helfenstein, F. Mattern, and T. Staake, 'Leveraging smart meter data to recognize home appliances', in 2012 IEEE International Conference on Pervasive Computing and Communications, Mar. 2012, pp. 190–197. doi: 10.1109/PerCom.2012.6199866.

[20] A. Srinivasan, K. Baskaran, and G. Yann, 'IoT Based Smart Plug-Load Energy Conservation and Management System', in 2019 IEEE 2nd International Conference on Power and Energy Applications (ICPEA), Apr. 2019, pp. 155–158. doi: 10.1109/ICPEA.2019.8818534.

[21] S. Aheleroff et al., 'IoT-enabled smart appliances under industry 4.0: A case study', Advanced Engineering Informatics, vol. 43, p. 101043, Jan. 2020, doi: 10.1016/j.aei.2020.101043.

[22] H. Automations, 'Smart Life Compatible Devices', Home Automation, Aug. 26, 2019. https://home-automations.net/smart-life-compatible-devices/ (accessed Sep. 09, 2022).

[23] T. S. Home, 'What can the Smart Life App do? | Discover the App', Talo Smart Home, Apr. 29, 2020. https://www.talosmarthome.com/blog/smart-life-app-en/what-can-the-smart-life-app-do/ (accessed Sep. 09, 2022).

[24] 'Insteon', Insteon. https://www.insteon.com (accessed Sep. 09, 2022).

[25] How to Set Up Your Insteon Hub (and Start Adding Devices), (2017). Accessed: Sep. 09, 2022. [Online Video]. Available: https://www.youtube.com/watch?v=VJ7j13kxS1o

[26] 'Features — Support Knowledgebase — Insteon'. https://www.insteon.com/support-knowledgebase/tag/Features (accessed Sep. 09, 2022).

[27] 'Zuli Smartplug | Smart Home Energy Monitor |'. https://www.jebiga.com/zuli-smartplug-smart-home-energy-monitor/ (accessed Sep. 09, 2022).

[28] 'Zuli Smartplugs by Zuli, Inc — Kickstarter'. https://www.kickstarter.com/projects/zuli/zuli-smartplugs?ref=category (accessed Sep. 09, 2022).

[29] 'How to Install the Sense Energy Monitor - Sense Blog'. https://blog.sense.com/articles/the-sense-installation-process/ (accessed Sep. 09, 2022).

[30] 'How Does Sense Detect My Devices? - Sense Blog'. https://blog.sense.com/articles/how-does-sense-detect-my-devices/ (accessed Sep. 09, 2022).

[31] 'Sense Features', Sense Home Energy Monitor. https://sense.com (accessed Sep. 09, 2022).

[32] S. Team, 'Sense Connects with Smart Plugs', Sense Blog, Nov. 13, 2018. https://blog.sense.com/smart-plug-integration (accessed Sep. 09, 2022).

[33] 'EnergyCloud®'. https://www.bluelineinnovations.com/ (accessed Sep. 09, 2022).

[34] 'EnergyCloud®'. https://www.bluelineinnovations.com/diy-details (accessed Sep. 09, 2022).

[35] 'EnergyCloud®'. https://www.bluelineinnovations.com/compatibility-window (accessed Sep. 09, 2022).

[36] 'EnergyCloud®'. https://www.bluelineinnovations.com/product-details (accessed Sep. 09, 2022).

[37] 'Secure and resizable cloud compute – Amazon EC2 – Amazon Web Services', Amazon Web Services, Inc. https://aws.amazon.com/ec2/ (accessed Sep. 10, 2022).

[38] K. Grgić, I. Špeh, and I. Heđi, 'A web-based IoT solution for monitoring data using MQTT protocol', in 2016 International Conference on Smart Systems and Technologies (SST), Oct. 2016, pp. 249–253. doi: 10.1109/SST.2016.7765668.

[39] 'Project Jupyter'. https://jupyter.org (accessed Sep. 10, 2022).

[40] 'Firebase'. https://firebase.google.com/?gclid=CjwKCAiA78aNBhAlEiwA7B76p5 nVoIaEEdVogO (accessed Sep. 10, 2022).

[41] 'Meet Android Studio', Android Developers. https://developer.android.com/studio/intro (accessed Sep. 10, 2022).

# Implementation of a Web System with Chatbot Service for Sales Management - A Review

Jorge Barrantes-Saucedo[1], Cristian García-Leandro[2], Orlando Iparraguirre-Villanueva[3] ,
Rosalynn Ornella Flores-Castañeda[4]

Facultad de Arquitectura e Ingeniería, Universidad César Vallejo, Lima, Perú[1, 2, 4]
Facultad de Ingeniería-Universidad Tecnológica del Perú, Chimbote, Perú[3]

*Abstract*—The objective of the research was to analyze various researches about web systems with chatbot service in the sales management process between the years 2018-2022, employing four databases, such as: Science Direct, Taylor & Francis, IEEE Xplore and Springer. The PRISMA methodology was applied, selecting 60 manuscripts where the year of highest publication was 2021 (35%), leading the USA as the country with the highest scientific production equivalent to 23.33%; in addition, the type of research that predominated were scientific articles with the percentage value of 70% and being entirely in the English language. Finally, it was found that there are two relevant components regarding the implementation of a web system with chatbot service for Sales Management, the first are the evaluated aspects, explained as those that focus on the analysis of the intelligent system, chatbot, website, Google API, e-commerce, machine learning, IBM service, mobile application, web, relationship with customer service, sales management, digital transformation, information system, algorithm and innovation and as the second component, according to the conditional factors refers to the context in which the use of chatbot in sales management occurs, being such technical features as algorithm, type of system, chatbot-customer relationship, sales and innovation and sales-system relationship.

*Keywords*—*Web system; chatbot; chatbot service; sales management; sales automation*

## I. INTRODUCTION

In recent years, a great evolution has been identified at the enterprise level due to the cultural variations of most organizational entities, one of them being the use of technological tools focused on sales; however, there is insecurity on the part of management and collaborators on how to optimize processes using such tools [1]. Likewise, innovation in any organization is seen as a capacity and willingness to change on the part of the company, besides being influential in the success or failure of any entity; therefore, it is necessary to identify the factors that induce organizational innovation [2].

The sales process is constituted by two terms: sales and management, the former being considered as the art of planning while the latter is understood as a process in which sales are planned, directed, and controlled in each entity [3]. Consequently, success or failure depends on the sales force, so that decision making primarily affects the quality and ability to strengthen sales; however, most companies spend money on personal sales instead of investing in advertising and promotions, which is why it is necessary to raise awareness and prioritize economic investment in factors that allow every business entity to grow [4].

Therefore, continuous changes have transformed the way of doing things on a daily basis, with the arrival of the internet era has split the access to the information era by raising new requirements in the traditional sales model, considering the needs in the market whose objective is to provide services supported by IT tools for the automation of processes, as well as the organization and control of information [5]. Therefore, at the technological level, software construction ranges from static interfaces to dynamic functionalities, alluding to the website architecture, design, or client/server commands [6].

The technology uses chatbot services for the exchange of information between the user and the software that through the network allows achieving a purchase; therefore, they are considered as conversational software agents that carry out an easy process of dialect and automatic learning; however, it was identified that despite having a technological evolution, there is still an abandonment in online shopping given that it is deficient and confusing for users without having an advisor who can support them and give suggestions in their purchase process [7].

However, the process of buying and selling online is called e-commerce and this has increased and transformed the business aspect, establishing an optimal relationship between the customer and seller [8]. In Japan, salespeople work as a unit to meet the requirements; specifically, years of experience stand out, since the more years of experience, the greater the relationship between sales knowledge and performance, allowing inferring that the competitiveness of salespeople is reflected in the ability to learn through their experiences [9]. In this regard, the sales process involves handling a large volume of customer data, employers, products, and others; the good use of this information allows to achieve effective marketing in sales that through the passage of days achieve a positioning of the business entity and, therefore, optimal results [10].

Companies are facing an increasing challenge in sales management due to the need to maintain effective and constant interaction with customers in digital environments because online sales continue to expand. The problem focuses on the technical, strategic, and implementation challenges that companies may encounter when adopting this technology and balancing automation with human interaction in the online sales process. The questions posed in this research are three:

RQ1: What digital technologies allow the application of the web system in sales management? RQ2: What are the technological tools necessary for the application of the web system in sales management? And RQ3: What are the benefits of implementing a chatbot service in sales management?

This research is important to take advantage of the benefits of technology, improve efficiency, strengthen customer relationships, and remain competitive in an ever-changing business environment. The rationale for this research lies in the increasing relevance of this technology in today's business environment. Companies are looking to improve efficiency, deliver exceptional customer experiences, and stay competitive in an ever-changing marketplace. The adoption of chatbots is a growing technology trend that can contribute to these goals by optimizing resources, improving customer interaction and providing valuable data for decision making. Researching this implementation is essential to understand its benefits and challenges, contribute to knowledge in the field and promote innovation in sales management.

The objective of the research was to analyze the research related to web systems with chatbot service in the sales management process. This work is organized as follows: Section II specifies the methodology used for this type of research. Section III specifies the results obtained through tables and figures. Section IV delves into the discussion of the findings found and Section V concludes the research.

## II. METHODOLOGY

Systematic review can be conceptualized as the collection of evidence at a practical level to demonstrate the eligibility criteria previously specified to answer specific questions using systematic methods that are selected to minimize bias, generating reliable findings that allow the extraction of conclusions and optimal decision making; it is worth mentioning that the primary attributes are: criteria of choice, methodology, systematic search, and validity [11].

In this research, the collection of scientific literary material on a web system with chatbot service for sales management has been carried out in the period of 2018-2022. The collection process involved searching and selecting information based on the parameters established by the Prisma methodology [12]. For this, identification, eligibility, and inclusion criteria were considered. For the acceptance of scientific papers in this systematic review, the following aspects were considered:

- Date of publication belonging to the last decade (2018 - 2022) since it is considered as the appropriate period of antiquity to obtain adequate and accurate information about the conceptual constructs of the problem.

- Coming from scientific databases with a high level of reliability and originality, since it guarantees the scientific validity of what is described in this systematic review.

- Existence of words or phrases related to the chatbot and sales management, since this guarantees the relationship between the scientific documents found and the object of study.

- Writing in English, to obtain more information of an international nature related to the study variables.

For the discarding of scientific documents, the following aspects were considered:

- That the date of publication is prior to 2018, given that the information is considered outdated for the research purposes of a systematic review.

- That the research object of the documents found is not completely related to that of the present systematic review because, if so, it will not be helpful for the resolution of the current research question.

- It is too far from the one proposed for this inquiry, because, if so, the information described in those documents will not be of help for the relation of this systematic review.

In this sense, the following databases were considered in the search process:

- Taylor & Francis

- Science Direct

- IEEE Xplore

- Springer

As a first step, the search was performed using keywords such as "chatbot" and "sales management". After said search, the filter was applied according to the year of publication, considering for the research only those that were published between the years 2018 and 2022.

This resulted in the inclusion of 42 articles and 18 conferences under the papers structure, of which, after being filtered under criteria such as the linkage with the objective of study of this systematic review, the existence of keywords in the title that are related to the web system with chatbot service, as well as, sales management and the existence of a correct access link to the complete document in its digital format.

The documents included in the systematic review had the following distribution:

- Science Direct: From a total of 2,518 scientific articles, 10 were selected.

- Taylor & Francis: From a total of 758 scientific articles found, 12 were finally selected.

- IEEE Xplore: From a total of 1,627 scientific articles found, 15 were taken.

- Springer: Out of 7,129 articles found, 23 were selected.

After that, a list of the selected documents was made considering their source. Duplicates were checked and no document was found to be in more than one database. Finally, the documents were ordered according to aspects such as the country where the research was carried out, the year and type of publication, among others.

Fig. 1 shows the number of manuscripts identified in the search for information by database, following the parameters of the PRISMA methodology.
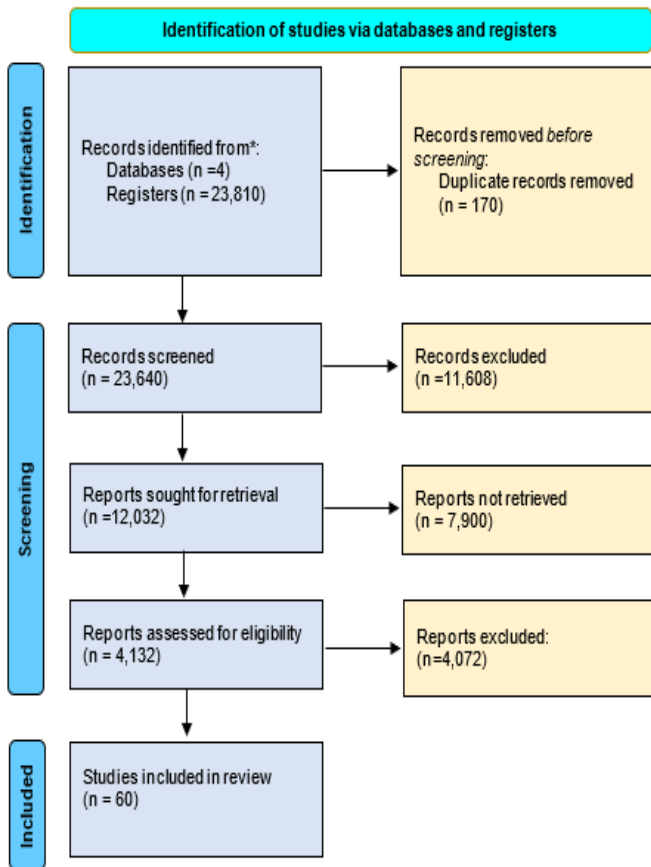


Fig. 1. PRISMA methodology.

## III. RESULTS

The results have been structured according to a database made up of 23,810 explorations, which after a severe analysis according to the established filters gave way to a database with methodological data made up of 60 studies. As shown in Fig. 3, the Preferred Reporting Items for Systematic reviews, and Meta-Analyses method, known by its acronym PRISMA, was applied to explain how and what results were generated with the literature review. Starting by identifying four bibliographic sources: Science Direct, Taylor and Francis, IEEE Xplore and Springer, as the first phase, identification, the first selection was carried out based on the search by key words and phrases, obtaining 23,810 inquiries, where 23.27% corresponded to Science Direct, 14.87% to Taylor & Francis, 10.66% to IEEE Xplore and 51.20% to Springer.

In the second phase, placing on screen, with the second selection criterion considering the year of publication, in this case from 2018 to 2022, there were 12,032 studies where 20.93% came from Science Direct, 6.30% from Taylor & Francis, 13.52% from IEEE Xplore and 57.25% from Springer. In the third phase, eligibility, the third selection was carried out considering the title with words or phrases related to the subject of the present systematic review, resulting in 7,900 documents excluded and 4,132 selected of the latter 29.48%

registered in Science Direct, 1.40% from Taylor & Francis, 17.59% from IEEE Xplore and 51.52% from Springer.

Finally, in the fourth phase, included, the criteria for reading the abstract (identification by components such as methodology and results found was applied to clarify the relevance of the study), relationship with the objective of the study (considering that it has the same unit of analysis and variables or constructs addressed) and correct access link (including how to identify an access link to the document) were incorporated, with 4042 documents excluded, and 60 documents selected. Of the latter 10 (17%) were from Science Direct, 12 (20%) from Taylor & Francis, 15 (25%) from IEEE Xplore and 23 (38%) from Springer.

Fig. 2 identifies the percentage of contribution to the information from each of the databases. The two databases with the highest contribution are Springer and IEEE Xplore, with a contribution of 38% and 25%, respectively. They are followed by Taylor & Francis with 20% and Science Direct with 17%.
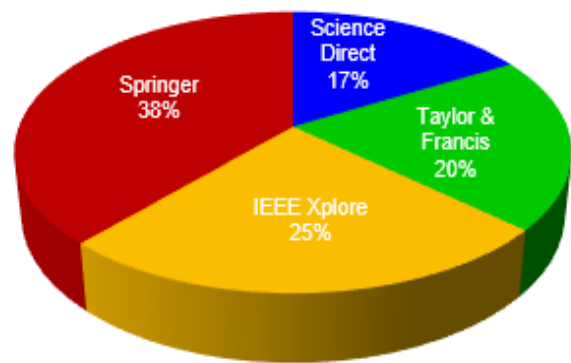


Fig. 2. Percentage data of the data bases.

The number of articles found was 23810, and after applying the exclusion criteria, 60 articles were found as shown in Fig. 3.
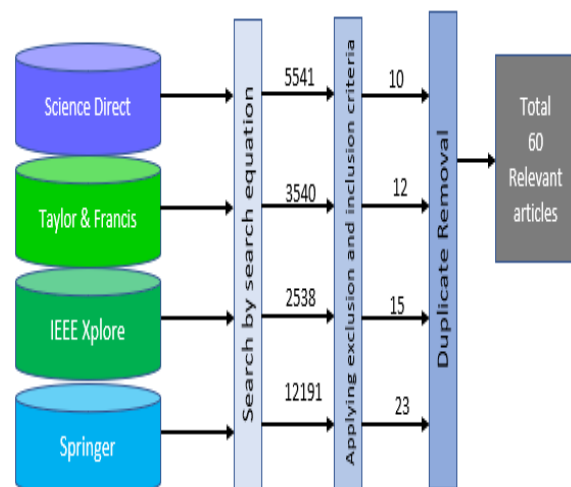


Fig. 3. Number of studies identified by each database.

Fig. 4 shows the selection process of studies identified in the databases considering four stages: identification, put on screen, eligibility and including. In the first stage 11778 were excluded because they did not meet the criteria of search by key words and phrases, in the second stage 7900 were excluded because they were not in the range of years of publications from 2018 to 2022, in the third stage 4072 manuscripts were excluded because they were not related to the research. Finally, 60 publications were selected.
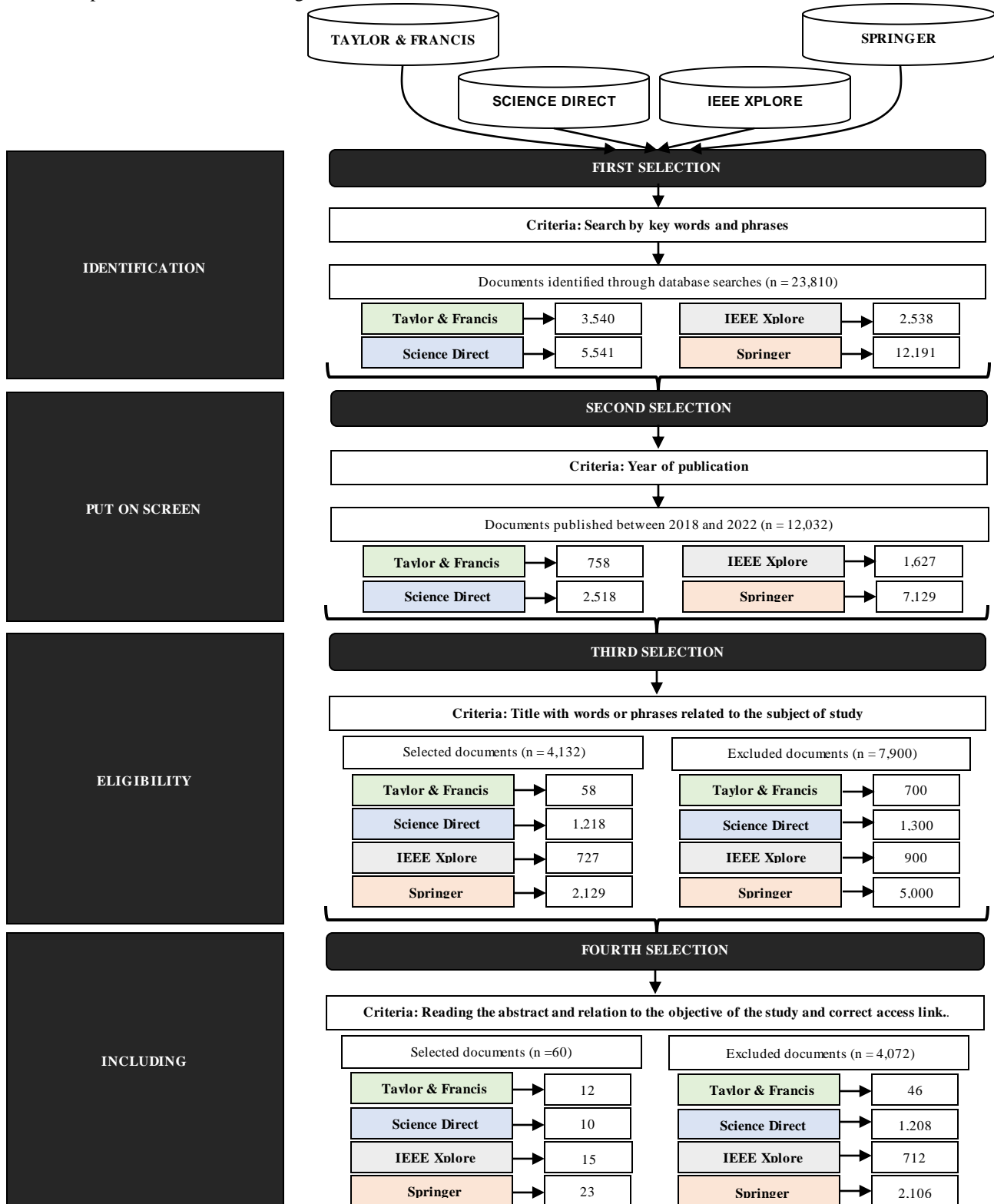


Fig. 4. Selection process of studies identified in the databases.

According to the analysis of the 42 articles and 18 conferences, 20% were published in 2018, followed by 15% in 2019, 13.33% in 2020, 35% in 2021 and 16.67% in 2022. Regarding the lines described above, 2021 was the year that had the greatest approach to the subject matter given that previous years there has been little scientific production; in the following year the percentage value decreases, as shown in Fig. 5.
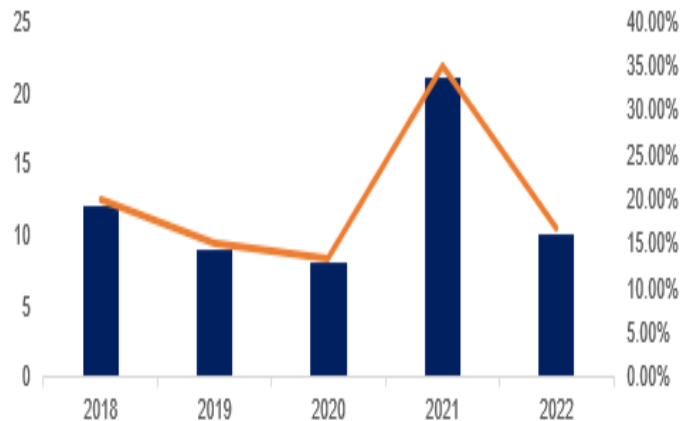


Fig. 5.   Documents included in the research by year of publication.

Also, accordingly, it was identified that in 2018 1.67% belong to Science Direct, 6.67% Taylor & Francis, 3.33% IEEE Xplore and 8.33% to Springer; in 2019 6.67% to Science Direct, 1.67% to Taylor & Francis, 3.33% to IEEE Xplore and Springer; in 2020 3. 33% to IEEE Xplore, 5% Taylor & Francis and Springer; in 2021 6.67% to Science Direct, 5% to Taylor & Francis, 11.67% to IEEE Xplore and Springer; finally, in 2022 1.67% represented Science Direct and Taylor & Francis, 3.33% to IEEE Xplore and 10% to Springer, such are seen in Fig. 6.
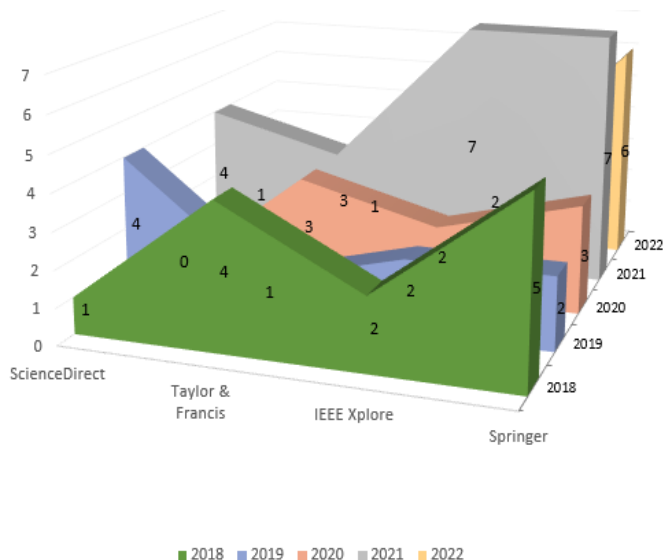


Fig. 6.   Documents included in the research according to year of publication and database.

Fig. 7 shows the research considered according to country, in which the USA leads in representation with 23.33%

equivalent to 14, followed far behind by India and Norway with 11.67% and 8.33%, respectively.
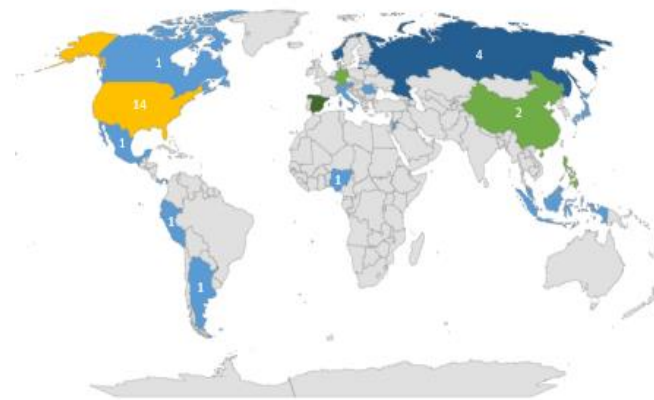


Fig. 7.   Documents included in the research according to country of origin grouped by continent.

Fig. 8 classifies the bibliography according to the type of research, with 42 articles (70%) and 18 (30%) conferences.
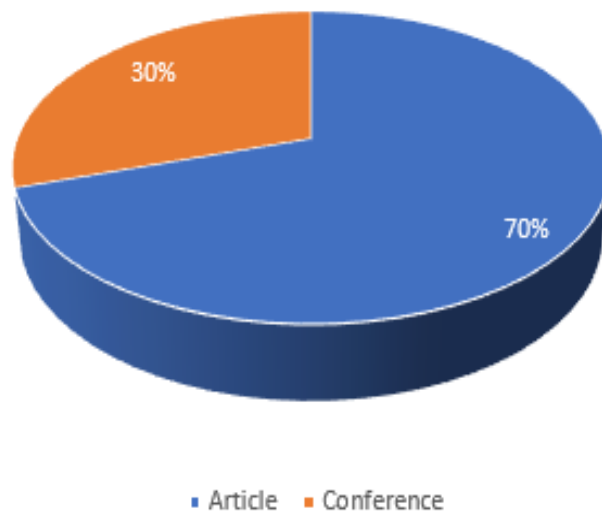


Fig. 8.   Documents included in the research according to bibliographic classification.
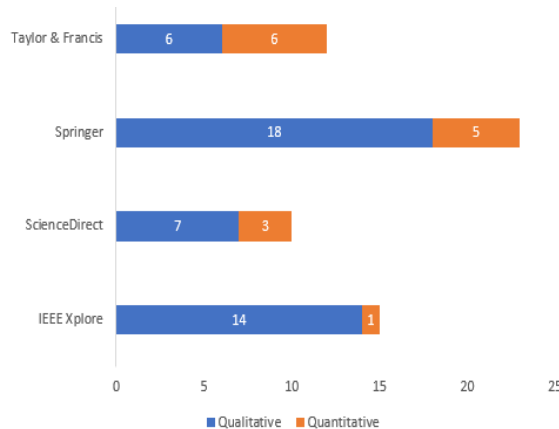


Fig. 9.   Documents included in the research according to research approach.

On the other hand, the studies have been classified according to the research approach according to the database, being from the qualitative approach 21.67% for IEEE Xplore, 11.67% for Science Direct, 10% for Taylor & Francis and 30% for Springer; likewise for the quantitative approach, 3.33% were identified for IEEE Xplore, 5% for Science Direct, 10% for Taylor & Francis and 8.33% for Springer. These results are shown in Fig. 9.

Table I presents each of the 60 authors of the researches addressed within the systematic review, where, based on the reading of each one, two relevant components were stipulated, on the one hand according to the aspects evaluated, explained as the one that focuses the analysis of the intelligent system, chatbot, website, Google API, its relationship with e-commerce, machine learning, IBM service, mobile application, web, relationship with customer service, sales management,

digital transformation, information system, algorithm and innovation.

As the second component, according to the conditional factors refers to the context in which the use of chatbot in sales management occurs, being such technical characteristics as algorithm, type of system, chatbot-customer relationship, sales and innovation and sales-system relationship.

Specifically, within the first component, 33.33% of the 60 studies addressed evaluated aspects of sales management, followed by 26.67% in chatbot, 6.67% in customer service, 3.33% in sales management and ERP, innovation, mobile application and web, ending with 1.67% in digital transformation, sales, Google API, intelligent system, information system, e-commerce, neural network, social networks, LSTM algorithm, artificial intelligence, machine learning and IBM service.

TABLE I.        ORIENTATION OF THE WEB SYSTEM APPLICATION UNDER TWO COMPONENTS

| Components: web-based system with chatbot service for sales management | | Reference |
|---|---|---|
| 1 | 2 | |
| According to evaluated aspects | According to conditioning factors | |
| Intelligent system, chatbot | Technical characteristics (algorithm, type of system) | [13] |
| Website, chatbot and Google API | Technical characteristics (algorithm, type of system) | [6] |
| Chatbot, system | Technical characteristics (algorithm, type of system) | [7] |
| Chatbot, e-commerce | Technical characteristics (algorithm, type of system) | [14] |
| Chatbot, machine learning | Technical characteristics (algorithm, type of system) | [15] |
| Mobile and web application | Technical characteristics (algorithm, type of system) | [16] |
| Mobile and web application | Technical characteristics (algorithm, type of system) | [17] |
| Chatbot and IBM service | Technical characteristics (algorithm, type of system) | [18] |
| Chatbot | Technical characteristics (algorithm, type of system) | [19] |
| Chatbot | Technical characteristics (algorithm, type of system) | [20] |
| Chatbot | Technical characteristics (algorithm, type of system) | [21] |
| Chatbot | Technical characteristics (algorithm, type of system) | [22] |
| Chatbot | Technical characteristics (algorithm, type of system) | [23] |
| Chatbot | Technical characteristics (algorithm, type of system) | [24] |
| Chatbot | Technical characteristics (algorithm, type of system) | [25] |
| Chatbot | Technical characteristics (algorithm, type of system) | [26] |
| Chatbot | Technical characteristics (algorithm, type of system) | [27] |
| Chatbot | Technical characteristics (algorithm, type of system) | [28] |
| Chatbot | Technical characteristics (algorithm, type of system) | [29] |
| Chatbot | Technical characteristics (algorithm, type of system) | [30] |
| Chatbot | Technical characteristics (algorithm, type of system) | [31] |
| Chatbot | Technical characteristics (algorithm, type of system) | [32] |
| Chatbot | Technical characteristics (algorithm, type of system) | [33] |
| Chatbot, customer service | Chatbot-customer relationship | [32] |
| Chatbot | Technical characteristics (algorithm, type of system) | [34] |
| Chatbot, dialogues | Technical characteristics (algorithm, type of system) | [35] |
| Chatbot, customer service | Chatbot-customer relationship | [8] |
| Chatbot, artificial intelligence language | Technical characteristics (algorithm, type of system) | [36] |

| Chatbot, customer service | Chatbot-customer relationship | [37] |
|---|---|---|
| Chatbot, customer service | Chatbot-customer relationship | [38] |
| Sales management | Relationship between sales and innovation | [39] |
| Sales management | Relationship between sales and innovation | [1] |
| Sales management, e-commerce, neural network | Sales and system relationship | [40] |
| Sales management | Relationship between sales and innovation | [41] |
| Sales management and social networks | Relationship between sales and innovation | [42] |
| Sales management | Relationship between sales and innovation | [3] |
| Sales management | Relationship between sales and innovation | [4] |
| Sales management | Relationship between sales and innovation | [43] |
| Sales management | Relationship between sales and innovation | [44] |
| Sales management and ERP | Relationship between sales and innovation | [45] |
| Sales management | Relationship between sales and innovation | [46] |
| Digital transformation, sal | Sales and system relationship | [47] |
| Sales management | Relationship between sales and innovation | [48] |
| Sales management | Relationship between sales and innovation | [49] |
| Sales management | Relationship between sales and innovation | [50] |
| Sales management | Relationship between sales and innovation | [51] |
| Sales management and innovation | Relationship between sales and innovation | [9] |
| Sales management | Relationship between sales and innovation | [52] |
| Sales management | Relationship between sales and innovation | [53]] |
| Sales management | Relationship between sales and innovation | [54] |
| Sales management, information system | Sales and system relationship | [50] |
| Sales management and web system | Sales and system relationship | [5] |
| Sales management | Relationship between sales and innovation | [55] |
| Sales management and ERP | Sales and system relationship | [56] |
| Sales management | Relationship between sales and innovation | [57] |
| Sales management and innovation | Relationship between sales and innovation | [58] |
| Sales management | Relationship between sales and innovation | [2] |
| Sales management | Relationship between sales and innovation | [59] |
| Sales management | Relationship between sales and innovation | [60] |
| Sales management and LSTM algorithm | Sales and system relationship | [10] |
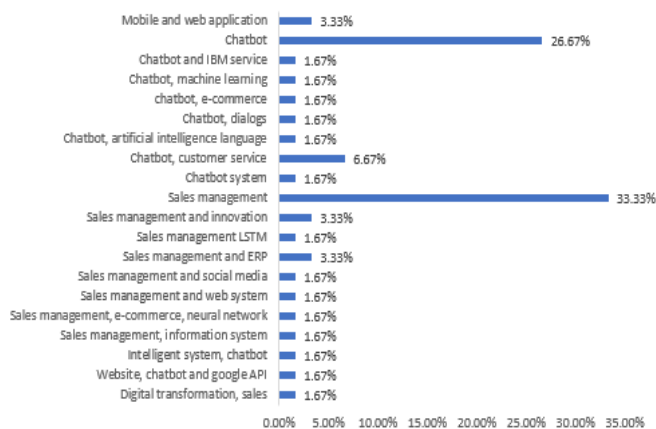


Fig. 10. Component 1: aspects evaluated.

Fig. 10. Count of documents included in the research, according to component 1: aspects evaluated.

Regarding the second component, 43.33% of the identified articles focused on mentioning about the technical characteristics of any web system with the chatbot service, such as the algorithm, software development methodology, APIS used and so on; while 38.33% refer to the relationship of sales management and innovation, as well as 11.67% for its relationship with the system and ending with 6.67% referring to the relationship of the chatbot with customer service.

Fig. 11. Count of documents included in the research, according to component 2: conditioning factors.
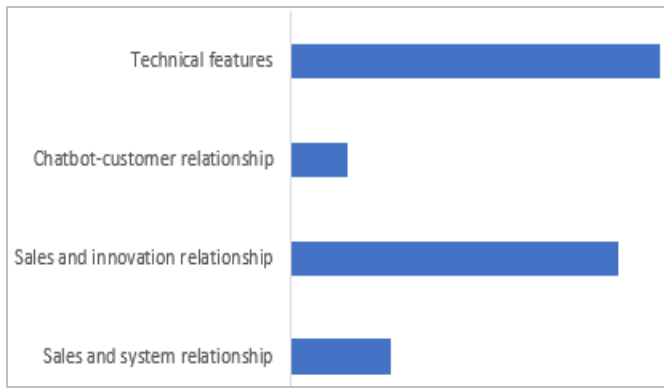
Fig. 11. Component 2: conditioning factors.

## IV.  DISCUSSION

RQ1: What digital technologies allow the application of the web system in sales management?

The implementation of a Web System with Chatbot Service for Sales Management involves the integration of several key digital technologies, such as Natural Language Processing (NLP), chatbots, Google API, Artificial Intelligence, similarity algorithms like Jaccard, intent recognition, usability evaluation, social penetration theory, DSSM and Regression Forest models, generative methods, SuperAgent with Seq2seq, Ad-hoc, Condor system, Tribefinder, Natural Language Processing techniques, domain ontologies, Chatfuel Bots, measurement tools such as Attrakdiff, web crawling, knowledge bases, AIML and technology acceptance models. These technologies work together to enable more efficient and effective interaction with users, improving the understanding of their needs and providing accurate answers in the context of sales management [6] [13] [15] [17] [18] [22] [25] [34] [36] [38]. Therefore, the analysis of the 60 selected research allowed concluding that the necessary technologies for the development of a system with chatbot service are those that make use of artificial intelligence to improve the processes within a company. However, in the systemic review not all of them use artificial intelligence, since it depends on the problem they want to solve.

Table II presents the digital technologies that allow the development of a web system.

RQ2: What are the technological tools necessary for the application of the web system in sales management?

In relation to this topic, it has been identified that in several studies analyzed, the most prominent tools are JavaScript, HTML, CSS, Bootstrap, front-end web development, SQLite, Laravel, PHP, MySQL, Dialogflow, Python, JSON, HCR, C#, and .NET. These tools play a key role in addressing the complexities of web systems development, providing efficient and robust solutions depending on the programming language used. The choice of these tools not only ensures the proper development of the web system, but also significantly influences its performance, scalability, and ease of maintenance.

The toolset ranges from the creation of the user interface, using technologies such as HTML, CSS, and Bootstrap, to the implementation of business logic using languages such as

JavaScript, PHP, and Python. In addition, databases such as SQLite and MySQL play an essential role in efficient data storage and retrieval. The integration of technologies such as Dialogflow enables the creation of chatbots, a crucial element in the context of the proposed system.

TABLE II.    DIGITAL TECHNOLOGIES THAT ENABLE THE DEVELOPMENT OF A WEB SYSTEM

| N° | Technology | Quantity | Reference |
|---|---|---|---|
| 1 | Natural Language Processing (NLP) Algorithm | 4 | [13] [14] [28] [15] |
| 2 | Google API | 1 | [6] |
| 3 | Artificial intelligence | 15 | [7] [16] [17] [18] [23] [29] [32] [8] [58] [30] [35] [31] [40] |
| 4 | Jacquard similarity algorithm | 1 | [15] |
| 5 | Intent recognition algorithm | 1 | [15] |
| 6 | Usability scal | 1 | [15] |
| 7 | Heuristic evaluation | 1 | [19] |
| 8 | Social penetration theory | 1 | [21] |
| 9 | DSSM Model | 1 | [22] |
| 10 | Regressioon forest model | 1 | [22] |
| 11 | Generative method | 1 | [24] |
| 12 | Ad-hoc | 1 | [24] |
| 13 | Condor tribefinder system | 1 | [25] |
| 14 | Bots chatfuel | 1 | [24] |
| 15 | Web tracking | 1 | [24] |
| 16 | AIML | 1 | [36] |
| 17 | Technology acceptance model | 1 | [38] |
| 18 | Intrusion Detection Algorithm | 1 | [40] |
| 19 | Contingency approach | 1 | [42] |
| 20 | DBSCAN Method | 1 | [50] |
| 21 | ERP, SOA | 1 | [57] |

It is important to emphasize that, although these tools have great potential and versatility, their choice should be based on the specific needs of the project and compatibility with the selected programming language. Each tool presents its own advantages and challenges, and it is crucial to evaluate how they complement each other to achieve a complete and effective web system. In this context, the right combination of these tools can be decisive for the successful development and implementation of web systems in various environments and applications [6] [14].

Table III presents the technological tools necessary for the implementation of the web system.

RQ3: What are the benefits of implementing a chatbot service in sales management?

The literature review of the last five years addressed the knowledge of sales management and chatbot, in which it was founded that the use of IT tools can improve the internal processes of a business entity regardless of the category to which they are dedicated, one of the benefits is to establish a

relationship between digital transformation, sales, innovation, e-commerce and machine learning [6] [13] [29]. Similarly, it was identified that the use of technological tools in purchasing, and sales processes leads to the growth of e-commerce and, consequently, to market positioning [14] [37] [61].

TABLE III.     Technological Tools Necessary for the Application of the Web System

| Nº | Technology | Quantity | Reference |
|----|------------|----------|-----------|
| 1 | JavaScript | 4 | [13] [6] |
| 2 | Front-end web development | 2 | [18] [6] |
| 3 | HTML | 2 | [18] [6] |
| 4 | CSS | 1 | [6] |
| 5 | Bootstrap | 1 | [6] |
| 6 | SQlite | 1 | [6] |
| 7 | Laravel | 1 | [14] |
| 8 | PHP | 1 | [14] |
| 9 | MySQL | 1 | [14] [28] |
| 10 | Dialogflow | 2 | [28] |
| 11 | Python | 1 | [15] |
| 12 | JSON | 1 | [15] |
| 13 | HCR | 1 | [21] |
| 14 | C# | 1 | [5] |
| 15 | .NET | 1 | [5] |

Therefore, day by day they are considered as important doors for the management of digital information in different areas; therefore, it is necessary to emphasize that their objective is to optimize the relevant processes at a business level [31], [32].

Likewise, it is stated that chatbots allow interaction in various contexts and streamlines them on a daily basis, i.e., it allows 24-hour customer service, provides required information, answers doubts and queries; that is why its implementation is considered quick and simple being useful for those who have not had any approach with technology [20] [19] [16] [23] [35] However, the speed of development can cause problems if tests are not performed to validate functionality and usability [21] [30] [31] [24].

In sales management, it was identified that most companies have initiated the use of cognitive chatbots to verify real-time information about the reliability and accessibility of products/services, automatic responses for a better customer experience [28] [50] [26]. Also, for their adaptation, it is paramount that users trust their use to provide the required support [38] [62] [11] [63].

It is also considered that e-commerce is increasingly threatened, and attacks are becoming more serious, frequent security incidents in the network have generated losses that when analyzed it is inferred that it must be safeguarded with security in the network for its solution [45] [53] [40]. Consequently, in this era there are a myriad of technologies that allow changes to be made to obtain greater productivity, efficiency, and quality [58].

## V.    Conclusions

It is concluded that the systematic review analyzed the theoretical and practical studies about the web system with chatbot service for sales management between the years 2018-2022 that by applying the inclusion and exclusion criteria only conforming a total of 42 articles and 18 conferences under the paper structure using PRISMA methodology, of which 10 (16.67%) were Science Direct articles, 12 (20%) Taylor & Francis articles, 15 (25%) IEEE Xplore conferences and 23 (38.33%) of them, 20 are articles and three conferences in Springer. In the studies it was identified that to carry out an optimal sales process it is necessary to consider strategies that can be achieved through a joint work by the company.

The development of this research allowed to explore the various studies that allow to explain and analyze the level of knowledge about web systems with chatbot service applied in the sales management process, from the identification of technological tools, programming languages; as well as the processes that influence sales management, the way of organization of the sales manager, collaborators and what is the perception of their customers against the traditional process and how it has been evolving.

Future research can delve deeper into the identification and evaluation of the technical requirements necessary for a successful implementation of chatbots in this context. This involves not only interaction with customers, but also integration with business management systems and e-commerce platforms. In addition, it would be valuable to explore how collaboration strategies between sales and technology development teams influence system design and effectiveness. This research could include case studies in various companies to analyze how the implementation of chatbots affects the efficiency of sales processes, customer satisfaction and overall company performance. Ultimately, the goal would be to establish practical guidelines and recommendations for the successful design and development of sales-oriented chatbot systems in today's business environment.

Finally, in reference to limitations include challenges in the complexity of human-machine interaction, technological challenges in terms of natural language processing and personalization, as well as the inability of chatbots to empathize and understand complex human situations. In addition, implementation, and maintenance costs, along with the need for continuous learning and the possibility of rejection by users, may influence the perception and acceptance of this technology. Data security, cultural change and employee training are also crucial factors to consider in this process. Understanding these limitations provides a solid foundation for addressing the challenges and making informed decisions in successfully integrating chatbots into sales management processes.

## References

[1] Rapp and L. Beeler, "The state of selling & sales management research: a review and future research agenda," https://doi.org/10.1080/10696679.2020.1860680, vol. 29, no. 1, pp. 37–50, 2021, doi: 10.1080/10696679.2020.1860680.

[2] L. J. Zmich, M. P. Groza, and M. D. Groza, "Organizational Innovativeness and Firm Performance: Does Sales Management

Matter?: An Abstract," Developments in Marketing Science: Proceedings of the Academy of Marketing Science, pp. 487–488, 2022, doi: 10.1007/978-3-030-89883-0_124/COVER.

[3] M. Helmold, "Sales Management," Management for Professionals, vol. Part F376, pp. 51–62, 2022, doi: 10.1007/978-3-031-10097-0_5/COVER.

[4] M. R. Czinkota, M. Kotabe, D. Vrontis, and S. M. R. Shams, "Selling and Sales Management," pp. 649–693, 2021, doi: 10.1007/978-3-030-66916-4_14.

[5] D. Wei and C. Jiang, "Design and Implementation of Automobile Sales Management Information System Based on C#.NET Technology," Proceedings - 6th International Conference on Computing Methodologies and Communication, ICCMC 2022, pp. 1493–1496, 2022, doi: 10.1109/ICCMC53470.2022.9753920.

[6] K. Kumari, A. Srivastava, and T. Sasikala, "Herbivicus: A Full Stack Website with Chatbot and Google API," Lecture Notes in Mechanical Engineering, pp. 635–647, 2022, doi: 10.1007/978-981-16-7909-4_59/COVER.

[7] D. P. P. Villanueva and I. Aguilar-Alonso, "A Chatbot as a Support System for Educational Institutions," ITMS 2021 - 2021 62nd International Scientific Conference on Information Technology and Management Science of Riga Technical University, Proceedings, 2021, doi: 10.1109/ITMS52826.2021.9615271.

[8] E. W. T. Ngai, M. C. M. Lee, M. Luo, P. S. L. Chan, and T. Liang, "An intelligent knowledge-based chatbot for customer service," Electron Commer Res Appl, vol. 50, p. 101098, Nov. 2021, doi: 10.1016/J.ELERAP.2021.101098.

[9] M. Matsuo, "Sales management: Learning and innovation in Japan," https://doi.org/10.1080/1046669X.2019.1658014, vol. 25, no. 4, pp. 241–244, 2019, doi: 10.1080/1046669X.2019.1658014.

[10] Y. Hu and B. Xu, "Medical Equipment Sales Management Prediction System Based on LSTM Algorithm," Lecture Notes on Data Engineering and Communications Technologies, vol. 102, pp. 157–164, 2022, doi: 10.1007/978-981-16-7466-2_17/COVER.

[11] M. Krnic Martinic, D. Pieper, A. Glatt, and L. Puljak, "Definition of a systematic review used in overviews of systematic reviews, meta-epidemiological studies and textbooks," BMC Med Res Methodol, vol. 19, no. 1, Nov. 2019, doi: 10.1186/S12874-019-0855-0.

[12] M. J. Page et al., "The PRISMA 2020 statement: an updated guideline for reporting systematic reviews," BMJ, vol. 372, Mar. 2021, doi: 10.1136/BMJ.N71.

[13] N. A. Al-Madi, K. A. Maria, M. A. Al-Madi, M. A. Alia, and E. A. Maria, "An Intelligent Arabic Chatbot System Proposed Framework," 2021 International Conference on Information Technology, ICIT 2021 - Proceedings, pp. 592–597, Jul. 2021, doi: 10.1109/ICIT52682.2021.9491699.

[14] J. M. Solis-Quispe, K. M. Quico-Cauti, and W. Ugarte, "Chatbot to Simplify Customer Interaction in e-Commerce Channels of Retail Companies," pp. 561–570, 2021, doi: 10.1007/978-3-030-68285-9_52.

[15] P. U. Usip, E. N. Udo, D. E. Asuquo, and O. R. James, "A Machine Learning-Based Mobile Chatbot for Crop Farmers," Communications in Computer and Information Science, vol. 1666 CCIS, pp. 192–211, 2022, doi: 10.1007/978-3-031-22950-3_15/COVER.

[16] S. C. Ancheta, S. J. Soria, C. Francisco, K. D. Antonio, and A. E. Catacutan-Bangit, "NUCare: A Framework for Mobile and Web Application for Online Consultation in One University in Manila," Proceedings - 2021 1st International Conference in Information and Computing Research, iCORE 2021, pp. 17–22, 2021, doi: 10.1109/ICORE54267.2021.00022.

[17] P. S. Arcilla, K. L. D. Domingo, A. Y. O. Joaquin, A. N. O. Ungos, and M. N. Jamis, "Framework for the mobile and web development of NU Guidance Service System (NUGSS)," Proceedings - 2021 1st International Conference in Information and Computing Research, iCORE 2021, pp. 157–162, 2021, doi: 10.1109/ICORE54267.2021.00047.

[18] R. Arias-Marreros, K. Nalvarte-Dionisio, and L. Andrade-Arenas, "Design of a Web System to Optimize the Logistics and Costing Processes of a Chocolate Manufacturing Company," International

Journal of Advanced Computer Science and Applications, vol. 12, no. 8, pp. 860–866, 2021, doi: 10.14569/IJACSA.2021.0120897.

[19] L. M. Sanchez-Adame, S. Mendoza, J. Urquiza, J. Rodriguez, and A. Meneses-Viveros, "Towards a Set of Heuristics for Evaluating Chatbots," IEEE Latin America Transactions, vol. 19, no. 12, pp. 2037–2045, Dec. 2021, doi: 10.1109/TLA.2021.9480145.

[20] E. Adamopoulou and L. Moussiades, "An Overview of Chatbot Technology," IFIP Adv Inf Commun Technol, vol. 584 IFIP, pp. 373–383, 2020, doi: 10.1007/978-3-030-49186-4_31/FIGURES/3.

[21] M. Skjuve, A. Følstad, K. I. Fostervold, and P. B. Brandtzaeg, "My Chatbot Companion - a Study of Human-Chatbot Relationships," Int J Hum Comput Stud, vol. 149, p. 102601, May 2021, doi: 10.1016/J.IJHCS.2021.102601.

[22] A. S. Lokman and M. A. Ameedeen, "Modern chatbot systems: A technical review," Advances in Intelligent Systems and Computing, vol. 881, pp. 1012–1023, 2019, doi: 10.1007/978-3-030-02683-7_75/COVER.

[23] A. P. Chaves and M. A. Gerosa, "How Should My Chatbot Interact? A Survey on Social Characteristics in Human–Chatbot Interaction Design," https://doi.org/10.1080/10447318.2020.1841438, vol. 37, no. 8, pp. 729–758, 2020, doi: 10.1080/10447318.2020.1841438.

[24] M. Nißen et al., "See you soon again, chatbot? A design taxonomy to characterize user-chatbot relationships with different time horizons," Comput Human Behav, vol. 127, p. 107043, Feb. 2022, doi: 10.1016/J.CHB.2021.107043.

[25] A. Przegalinska, L. Ciechanowski, A. Stroz, P. Gloor, and G. Mazurek, "In bot we trust: A new methodology of chatbot performance measures," Bus Horiz, vol. 62, no. 6, pp. 785–797, Nov. 2019, doi: 10.1016/J.BUSHOR.2019.08.005.

[26] E. Van den Broeck, B. Zarouali, and K. Poels, "Chatbot advertising effectiveness: When does the message get through?," Comput Human Behav, vol. 98, pp. 150–157, Sep. 2019, doi: 10.1016/J.CHB.2019.04.009.

[27] F. Clarizia, F. Colace, M. Lombardi, F. Pascale, and D. Santaniello, "Chatbot: An education support system for student," Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics), vol. 11161 LNCS, pp. 291–302, 2018, doi: 10.1007/978-3-030-01689-0_23/COVER.

[28] S. Perez-Soler, S. Juarez-Puerta, E. Guerra, and J. De Lara, "Choosing a Chatbot Development Tool," IEEE Softw, vol. 38, no. 4, pp. 94–103, Jul. 2021, doi: 10.1109/MS.2020.3030198.

[29] L. K. Fryer, K. Nakao, and A. Thompson, "Chatbot learning partners: Connecting learning experiences, interest and competence," Comput Human Behav, vol. 93, pp. 279–289, Apr. 2019, doi: 10.1016/J.CHB.2018.12.023.

[30] J. Feine, U. Gnewuch, S. Morana, and A. Maedche, "Gender Bias in Chatbot Design," Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics), vol. 11970 LNCS, pp. 79–93, 2020, doi: 10.1007/978-3-030-39540-7_6/COVER.

[31] T. P. Nagarhalli, V. Vaze, and N. K. Rana, "A Review of Current Trends in the Development of Chatbot Systems," 2020 6th International Conference on Advanced Computing and Communication Systems, ICACCS 2020, pp. 706–710, Mar. 2020, doi: 10.1109/ICACCS48705.2020.9074420.

[32] A. Følstad, C. B. Nordheim, and C. A. Bjørkli, "What makes users trust a chatbot for customer service? An exploratory interview study," Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics), vol. 11193 LNCS, pp. 194–208, 2018, doi: 10.1007/978-3-030-01437-7_16/COVER.

[33] G. Daniel, J. Cabot, L. Deruelle, and M. Derras, "Xatkit: a Multimodal Low-Code Chatbot Development Framework," IEEE Access, vol. 8, pp. 15332–15346, 2020, doi: 10.1109/ACCESS.2020.2966919.

[34] T. L. Smestad and F. Volden, "Chatbot personalities matters: Improving the user experience of chatbot interfaces," Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics), vol. 11551 LNCS, pp. 170–181, 2019, doi: 10.1007/978-3-030-17705-8_15/COVER.

[35] K. Kvale, O. A. Sell, S. Hodnebrog, and A. Følstad, "Improving Conversations: Lessons Learnt from Manual Analysis of Chatbot Dialogues," Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics), vol. 11970 LNCS, pp. 187–200, 2020, doi: 10.1007/978-3-030-39540-7_13/COVER.

[36] S. F. Suhel, V. K. Shukla, S. Vyas, and V. P. Mishra, "Conversation to Automation in Banking through Chatbot Using Artificial Machine Intelligence Language," ICRITO 2020 - IEEE 8th International Conference on Reliability, Infocom Technologies and Optimization (Trends and Future Directions), pp. 611–618, Jun. 2020, doi: 10.1109/ICRITO48877.2020.9197825.

[37] I. K. F. Haugeland, A. Følstad, C. Taylor, and C. Alexander, "Understanding the user experience of customer service chatbots: An experimental study of chatbot interaction design," Int J Hum Comput Stud, vol. 161, p. 102788, May 2022, doi: 10.1016/J.IJHCS.2022.102788.

[38] R. K. Behera, P. K. Bala, and A. Ray, "Cognitive Chatbot for Personalised Contextual Customer Service: Behind the Scene and beyond the Hype," Information Systems Frontiers 2021, pp. 1–21, Jul. 2021, doi: 10.1007/S10796-021-10168-Y.

[39] S. L. Malek, S. Sarin, and B. J. Jaworski, "Sales management control systems: review, synthesis, and directions for future exploration," https://doi.org/10.1080/08853134.2017.1407660, vol. 38, no. 1, pp. 30–55, Jan. 2018, doi: 10.1080/08853134.2017.1407660.

[40] S. Zhang, J. Yang, T. Wang, and C. Wang, "Network Security Design of E-commerce Sales Management System Based on Neural Network Algorithm," Lecture Notes on Data Engineering and Communications Technologies, vol. 123, pp. 199–207, 2022, doi: 10.1007/978-3-030-96908-0_25/COVER.

[41] M. D. Groza, L. J. Zmich, and R. Rajabi, "Organizational innovativeness and firm performance: Does sales management matter?," Industrial Marketing Management, vol. 97, pp. 10–20, Aug. 2021, doi: 10.1016/J.INDMARMAN.2021.06.007.

[42] W. A. Schrock, Y. Zhao, K. A. Richards, D. E. Hughes, and M. S. Amin, "On the nature of international sales and sales management research: a social network–analytic perspective," https://doi.org/10.1080/08853134.2018.1428493, vol. 38, no. 1, pp. 56–77, Jan. 2018, doi: 10.1080/08853134.2018.1428493.

[43] W. A. Schrock, D. E. Hughes, Y. Zhao, C. Voorhees, and J. R. Hollenbeck, "Self-oriented competitiveness in salespeople: sales management implications," J Acad Mark Sci, vol. 49, no. 6, pp. 1201–1221, Nov. 2021, doi: 10.1007/S11747-021-00792-0/METRICS.

[44] S. Misra, "Selling and sales management," vol. 1, pp. 441–496, Jan. 2019, doi: 10.1016/BS.HEM.2019.07.001.

[45] A. K. Adriansyah and A. Y. Ridwan, "Developing Sales Management Sustainability Monitoring based on ERP System," 6th International Conference on Interactive Digital Media, ICIDM 2020, Dec. 2020, doi: 10.1109/ICIDM51048.2020.9339672.

[46] E. A. Pyanikova, A. E. Kovaleva, and M. A. Zaikina, "Sales Management Mechanism and Methodologies for Solving the Problems of Special-Purpose Product Management and Sales," Springer Proceedings in Business and Economics, pp. 333–340, 2018, doi: 10.1007/978-3-319-71876-7_29/COVER.

[47] M. Mattila, M. Yrjölä, and P. Hautamäki, "Digital transformation of business-to-business sales: what needs to be unlearned?," https://doi.org/10.1080/08853134.2021.1916396, vol. 41, no. 2, pp. 113–129, 2021, doi: 10.1080/08853134.2021.1916396.

[48] N. V. Razmochaeva, D. M. Klionskiy, and V. V. Chernokulsky, "The Investigation of Machine Learning Methods in the Problem of Automation of the Sales Management Business-process," Proceedings of the 2018 International Conference "'Quality Management, Transport and Information Security, Information Technologies'", IT and QM and IS 2018, pp. 376–381, Nov. 2018, doi: 10.1109/ITMQIS.2018.8525008.

[49] R. Dugan et al., "Sales management, education, and scholarship across cultures: early findings from a global study and an agenda for future research," https://doi.org/10.1080/08853134.2020.1781649, vol. 40, no. 3, pp. 198–212, Jul. 2020, doi: 10.1080/08853134.2020.1781649.

[50] N. V. Razmochaeva and D. M. Klionskiy, "Data presentation problems in retail sales management task," Proceedings of 2019 22nd International Conference on Soft Computing and Measurements, SCM 2019, pp. 244–247, May 2019, doi: 10.1109/SCM.2019.8903915.

[51] R. E. Plank, D. A. Reid, S. E. Koppitsch, and J. Meyer, "The sales manager as a unit of analysis: a review and directions for future research," https://doi.org/10.1080/08853134.2017.1423230, vol. 38, no. 1, pp. 78–91, Jan. 2018, doi: 10.1080/08853134.2017.1423230.

[52] D. Rangarajan, A. Sharma, B. Paesbrugghe, and R. Boute, "Aligning sales and operations management: an agenda for inquiry," https://doi.org/10.1080/08853134.2018.1450148, vol. 38, no. 2, pp. 220–240, Apr. 2018, doi: 10.1080/08853134.2018.1450148.

[53] M. Riester, F. Ansari, M. Foerster, and K. Matyas, "A Procedural Model for Utilizing Case-Based Reasoning in After-Sales Management," Lecture Notes on Multidisciplinary Industrial Engineering, vol. Part F42, pp. 294–301, 2022, doi: 10.1007/978-3-030-97947-8_39/COVER.

[54] A. A. Rapp, J. A. Petersen, D. E. Hughes, and J. L. Ogilvie, "When time is sales: the impact of sales manager time allocation decisions on sales team performance," https://doi.org/10.1080/08853134.2020.1717961, vol. 40, no. 2, pp. 132–148, Apr. 2020, doi: 10.1080/08853134.2020.1717961.

[55] C. Zheng Yang, S. Ramiah, and D. Padmakumar, "Web-based Agricultural Monitoring and Sales Management System," MysuruCon 2022 - 2022 IEEE 2nd Mysore Sub Section International Conference, 2022, doi: 10.1109/MYSURUCON55714.2022.9972406.

[56] A. Nowroth, "Sales Management: A Guide to Creating a Long-term Performance Culture," Sales and Business Models in the Logistics Industry, pp. 61–84, 2023, doi: 10.1007/978-3-658-39756-2_3.

[57] S. Vijaivargia and H. K. Garg, "A Framework of Lean ERP Focusing MSMEs for Sales Management," Advances in Intelligent Systems and Computing, vol. 841, pp. 683–689, 2019, doi: 10.1007/978-981-13-2285-3_80/COVER.

[58] N. Syam and A. Sharma, "Waiting for a sales renaissance in the fourth industrial revolution: Machine learning and artificial intelligence in sales research and practice," Industrial Marketing Management, vol. 69, pp. 135–146, Feb. 2018, doi: 10.1016/J.INDMARMAN.2017.12.019.

[59] V. Good, E. B. Pullins, and M. Rouziou, "Persisting changes in sales due to global pandemic challenges," https://doi.org/10.1080/08853134.2022.2132399, vol. 42, no. 4, pp. 317–323, 2022, doi: 10.1080/08853134.2022.2132399.

[60] N. N. Hartmann, H. Wieland, S. L. Vargo, and M. Ahearne, "Advancing sales theory through a holistic view: how social structures frame selling," https://doi.org/10.1080/08853134.2020.1838916, vol. 40, no. 4, pp. 221–226, Oct. 2020, doi: 10.1080/08853134.2020.1838916.

[61] C. Yuan and H. Yang, "Research on K-Value Selection Method of K-Means Clustering Algorithm," J 2019, Vol. 2, Pages 226-235, vol. 2, no. 2, pp. 226–235, Jun. 2019, doi: 10.3390/J2020016.

[62] R. Escobar, L. Juarez, E. Molino-Minero-Re, and A. Neme, "An Algorithm to Detect Variations in Writing Styles of Columnists After Major Political Changes," Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics), vol. 12469 LNAI, pp. 3–16, 2020, doi: 10.1007/978-3-030-60887-3_1/COVER.

[63] A. Nowroth, "Sales Management: A Guide to Creating a Long-term Performance Culture," Sales and Business Models in the Logistics Industry, pp. 61–84, 2023, doi: 10.1007/978-3-658-39756-2_3.

# Deep Learning Driven Web Security: Detecting and Preventing Explicit Content

Ganeshayya Shidaganti, Shubeeksh Kumaran, Vishwachetan D, Tejas B N Shetty

Dept. of Computer Science and Engineering, M S Ramaiah Institute of Technology, Bangalore, Karnataka, India

*Abstract*—In today's digital age, the vast expanse of online content has made it increasingly accessible for users to encounter inappropriate text, images and videos. The repercussions of such exposure are concerning, impacting individuals and society adversely. Exposure to violent content can lead to undesirable human emotions, including desensitization, aggression, and other harmful effects. We utilize a machine learning approach aimed at real-time violence detection in text, images and videos embedded in the website. The foundation of this approach lies in a deep learning model, highly trained on a vast dataset of manually labeled images categorized as violent or non-violent. The model boasts exceptional accuracy in identifying violence in images, subsequently filter out violent content from online platforms. By performing all processing intensive tasks in the Cloud, and storing the data in a database, an improved user experience is achieved by completing all the necessary detection processes at a lower time frame, and also reducing the processing load on the user's local system. The detection of the violent videos is done by a CNN model, which was trained on violent and non-violent video data, and the detection of emotions in the text is taken in by a NLP based algorithm. By implementing this highly efficient approach, web safety can undergo a significant improvement. Users can now navigate the web with confidence, free from concerns about accidentally encountering violent content, fostering improved mental health, and cultivating a more positive online environment. We are able to achieve 67% accuracy in detecting violent content at approximately 2.5 seconds at its best scenario.

*Keywords*—*Web safety; machine learning; cloud computing; natural language processing; web-scraping, big data*

## I. INTRODUCTION

The Internet has become an integral part of modern life, transforming the way we access information, communicate, and interact with the world. However, with its many advantages, the digital realm also presents various challenges, especially in terms of ensuring network security for users. One of the greatest concerns is the proliferation of overt cases of violence which pose a significant risk, particularly to vulnerable individuals such as children and adolescents. To address this critical issue, we propose a novel approach that uses machine learning techniques, specifically a natural language processing technique for text processing and deep learning Convolutional Neural Network (CNN), propose real-time disturbance detection in images and videos. The unrestricted access to the internet has led to an increase in explicit violent content on online platforms. This disturbing trend poses serious risks to users, ranging from psychological injury to desensitization to violence. In addition, children and young people exposed to such substances that can have long-

term negative effects on their mental and emotional well-being. Existing manual filtering methods and traditional keyword-based methods are often unable to effectively identify and prevent violent events, requiring advanced automated solutions. Insights into how the Internet has changed as a communication tool and the expanding demand for site filtering services was inferred from [1]. The suggested real-time violence detection system, which aims to combat dangerous and inappropriate information on the Internet, was motivated by this concept. From [2] a deep understanding of the difficulties brought about by the enormous volume of data and the persistent infractions on social media platforms can be obtained. The decision to use deep learning for real-time violence detection was motivated by this realization because it would effectively filter content without only depending on human interaction. [3] Shed some light on the growing use of algorithmic content filtering systems for popular websites like Facebook, YouTube, and Twitter. In response to the growing demand for efficient content filtering, we decided to use similar technical methods for real-time violence detection based on this knowledge.

The inspiration from [4] which suggested classifying web pages using artificial neural networks as a part of content filtering. In the beginning we started with a deep learning Convolutional Neural Network (CNN) model for identifying explicit information in web photos as we realized the potential of neural networks for in-the-moment content analysis. Comparative scarcity of research on detecting aggressive/violent behaviors and fights within video content was highlighted in [4]. This knowledge informed the choice to concentrate on violence detection since we recognized its usefulness in situations like the proposed real-time web safety system, when identifying explicit content is crucial. Inspired by the proposed method's utilization of extreme acceleration patterns as discriminant features in [5], we used similar ideas into the CNN model. By implementing this method, the accuracy of the violence identification by a large margin and displayed the potential of using the unique qualities of violent behaviors for better content filtering. The goal of developing a highly accurate and efficient violence detection system was in line with [6]'s emphasis on the use of local spatio-temporal elements in characterizing multimedia information. We were able to improve the system's capacity to differentiate between violent behaviors and regular activities by incorporating this understanding the CNN model, hence enhancing content filtering precision.

The main objective of this research is to enhance web security using a real-time violence detection system that

automatically filters and filters images with obvious violent content using the power of machine learning, we aim to create efficient and accurate solutions. The proposed method has two main steps. In the first step, a web page listener on the user's machine picks up the link from the visited web page and sends it to the server. The server checks its database to see if the website has been previously tagged or indexed for explicit content. If the content is available, it is immediately redirected to the user's device, and if there is violent content, the site is invisible. In the second stage, information about web pages that are not listed in the database is forwarded to the cloud computing service. There, images from various websites are processed using CNN's deep image learning algorithm, which is trained to detect clutter in images. The search results are then sent back to the server, where the web page information is added to the database. The results are then transmitted to the user's device, making clear images unrecognizable in real time. The proposed machine learning-based violence detection system has a great potential to significantly affect web security and protect users from obviously harmful content through the violence detection method an automated and incorporating real-time responses, the system ensures instant protection and enables users to have a secure online experience. Furthermore, the research contributes to the growing field of applying machine learning techniques to content filtering, paving the way for more advanced solutions in the future.

## II. LITERATURE REVIEW

Through a thorough study of important research papers, this literature review aims to highlight the symbiotic link between deep learning, cloud computing, and real-time communication. Collectively, the chosen papers highlight how these technologies have a revolutionary effect on a variety of applications, shedding light on how their integration promotes creativity, improves efficiency, and lessens difficulties in a variety of fields.

The methodology was heavily motivated by the [7]'s classification of violence detection algorithms based on conventional machine learning, support vector machine (SVM), and deep learning techniques. Within the limits of the framework offered by the evaluated classification techniques, we customized and updated the deep learning CNN model for violence detection. The research in [8] had an unique approach of eliminating violent scenes from movies through a three-step process that stood-out with the content filtering objective. To ensure quick and accurate detection of explicit content, we utilized a similar technique of analyzing frames and applying deep learning for violent detection, but in the context of web pages as opposed to movies.

The method of using a deep learning CNN model for violence detection was motivated with the research involving fully connected networks and long short-term memory (LSTM) networks for frame-level violence detection as seen in [9]. The idea of showing the features through attention mechanisms influenced the enhancement approach for recognizing explicit/violent content in real-time, even though the focus is on web content and not video frames. The development of models for accurate face recognition, such as the multi-foot input CNN model and the SPP-based CNN model in [10],

combined with the view on picture analysis and identification in the real-time violence detection system. The idea of improving accuracy through specialized CNN models influenced the optimization methods for content filtering, even though the concentration is on content rather than faces. The urge to develop a system that reduces such mistakes was influenced by [11]'s acknowledgment of the difficulty presented by false positives in violence detection, evidently those brought on by friendly behaviors. The strategy for improving the accuracy and applicability of the real-time system was inspired by the paper's presentation of three deep learning-based models for violence detection, including those based on transfer learning and training from scratch. The optimization methods for developing a highly reliable and effective violence detection system were influenced by the [12]'s assessment of improvements in CNNs, including layer design, activation functions, loss functions, regularization, optimization, and fast computation.

The understanding of the difficulties involved in delivering an easy-to-use access to information in different situations was influenced by [13] in examination of the mobility features in mobile client-server computing. This influenced how we approached developing a real-time violence detection system that takes into consideration the various situations in life in which people access web material. The study in [14] highlighted the critical working of client-server systems in information technology view, including a range of tasks like web-based applications, unified computing, mobile apps, and cloud computing. We understood the importance of both logical and physical components, such as programming scripts and networking, in providing effective and accurate content filtering. The architectural design choices were influenced by the [15]'s study of issues including the in-depth learnings of responsibilities between clients and servers and the thinking of client/server systems. In order to ensure the effectiveness and efficiency of the real-time violence detection system, we understood how important it was to assign defined tasks and organize the system to become more efficient. The overarching objective revolves around ensuring a seamless and efficient link between the real-time violence detection system and the clientele. This objective harmonizes with the insights from study [16], which illuminates the role of Web sockets as a conduit for establishing dynamic two-way communication within HTML5 compliant browsers. The emphasis on the singular socket prowess of Web sockets profoundly informed the system's design blueprint. Notably, the techniques for optimizing the construction of a real-time violence detection system drew inspiration from the principles elucidated by the works of [17]. These principles, underscored by a devotion to minimal latency and expansive scalability in the realm of web sockets, were intricately woven into the developmental fabric.

Light is shed on cloud computing's transformational effects and its ability to use machine learning methods in [18]. This understanding is in line with how we use cloud computing to combine deep learning CNN models for real-time violence detection and content filtering. The idea of using cloud computing for deploying and managing deep learning models was in line with the [19]'s analysis of the effects of cloud computing on the area of machine learning. Its examination of

parallelization using cutting-edge parallel computing frameworks like MapReduce, CUDA, and Dryad helped us better grasp how to analyze large data sets quickly. As managing vast amount of data is essential for precise content analysis, this realization was in line with the intention to apply deep learning CNN models for real-time violence detection. The research in [20] stressed the significance of reliability in cloud computing systems, admitting that errors are unavoidable even with architectures built for high service availability. We understood the importance of locating critical characteristics that are associated with application failures because doing so would help us better manage computational resources and mitigate wasteful resource consumption as a result of failed tasks. The study in [21] focuses on the difficulties associated with computationally effective data-driven prognostics and health management (PHM) was in line with the goal of effectively processing and analyzing massive amounts of web content in real time using cloud-based data management solutions. The research in [22] provided a comprehensive survey, which highlighted the challenges and future directions in this area, and [23] proposed a text classification approach, achieving an excellent performance on a benchmark dataset. Table I represents the comparative analysis and limitations of existing approaches as in [24], [25], [26] that this study is trying to overcome.

TABLE I.        COMPARISON AND ANALYSIS OF MODULAR APPROACHES

| Feature | [24] | [25] | [26] |
|---|---|---|---|
| Focus | Explicit content detection | Audio-visual-textual cyberbullying detection | Cyberbullying detection and prevention |
| Methods | Rule-based, machine learning | Deep learning | Data mining, psychological perspective |
| Findings | Rule-based methods are effective for detecting explicit content, but machine learning methods can achieve higher accuracy. | Deep learning methods can be effective for detecting cyberbullying across multiple modalities. | Data mining and psychological methods can be used to identify cyberbullying behaviour. |
| Limitations | Rule-based methods can be difficult to maintain as new forms of explicit content emerge. | Although powerful, deep learning methods can be computationally expensive. | Data mining methods can be difficult to interpret. |

The knowledge gained from these foundational publications guides the future work because deep learning, cloud computing, and real-time communication are all interconnected in this context. The lessons learned from the studied works give us a wealth of strategic viewpoints, practical suggestions and methodological strategies.

## III.    SYSTEM ARCHITECTURE

The system architecture is explained in three parts, Client-Side Setup, Server hosted Database, Cloud Computing as visually represented in Fig. 1.

### A.  Client-Side Setup

A node-JS based setup is chosen due to its ability to run on the user's inbuilt Chrome Browser with event listeners for extraction of Text, Images and Videos as and when the data is being loaded on the application. This is achieved using the Puppeteer modules that gives us the access to the requires data even before it appears on the user's screen. By using this module, we have more control over the happenings of this browser instance in real-time. This is a more convenient approach as opposed to other implementations where an iframe where the content of a website is being broadcasted into a container of the service provider's website and then host the processed website in a third-party browser. This does not just make the entire process tedious, but also causes delays throughout the user's browsing experience.
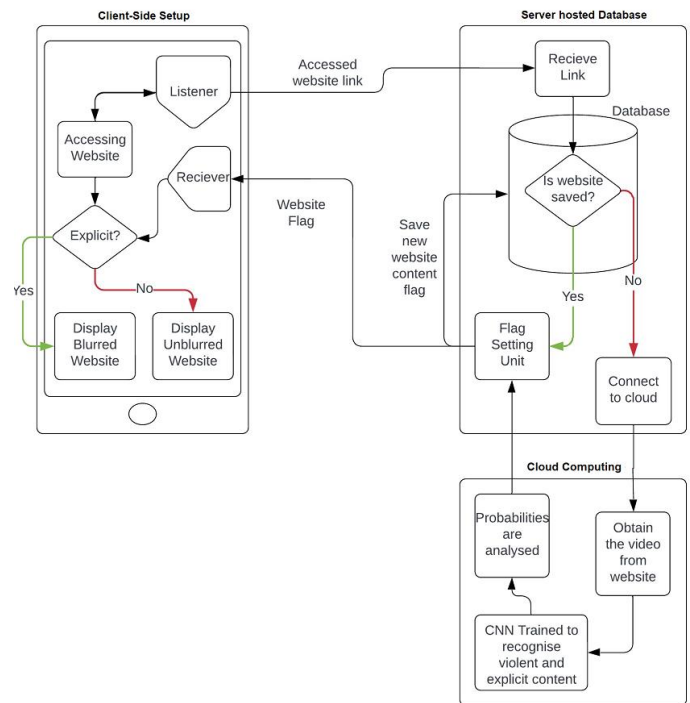


Fig. 1.   System architecture.

### B.  Server Hosted Database

The website data in the database is accessed via a hosted server connected to the Node-JS program firing the client's website. This server is responsible for handling URL inputs from the client and responding with safety-related information about the accessed websites either by going through the Database list, or by performing ML based Data analysis. This analysis is made on a Cloud Computer equipped to perform resource-intensive computations efficiently which directly updates the database in the Server. This dynamic process ensures that the database remains in a state of continuous enhancement, after every process and increase the accuracy over time.

### C.  Cloud Computing

Amazon AWS machine learning services provides both a cost effective and high-performance infrastructure. By deploying a Natural Language Processing and CNN model-

based ML programs in this platform, we achieve optimal performance to obtain a seamless user experience without utilizing local processing resources at all. AWS's Auto scaling capabilities allows the system to dynamically adjust resources based on demand, maintaining efficiency while avoiding unnecessary costs. The Amazon S3 storage solution ensures highly reliable data storage. Meanwhile AWS Lambda is a server less computing service that supports event driven executions. Key specifications and features to consider when deploying ML programs based on using Amazon AWS machine learning services are in Table II.

TABLE II.   AWS FEATURES OPTED

| Specification/Feature | Description |
|---|---|
| Instance Types | Choose compute-optimized instances (e.g., C5, M5) for efficient ML processing. |
| Auto Scaling | Implement dynamic resource adjustments to match varying workload requirements. |
| Storage Solutions | Leverage Amazon S3 for reliable and scalable data storage. |
| AWS Lambda | Utilize serverless computing for event-driven ML executions. |
| Amazon Sage Maker | Explore a managed service for end-to-end ML development and deployment. |
| Elastic Inference | Optimize inference performance and cost with GPU acceleration. |
| GPU Instances | For CNN-based models, consider GPU-equipped instances for enhanced performance. |
| AWS Lambda Edge | Use edge computing for low-latency execution near users. |
| AWS Step Functions | Orchestrate complex workflows for ML data processing and analysis. |
| AWS Data Analytics | Explore data analysis services for extracting insights from ML results. |
| AWS Cost Management | Monitor and control costs with AWS Cost Explorer and Budgets. |

## IV. METHODOLOGY

In this section, we outline the step-by-step methodology employed to realize the proposed real-time violence detection system. As represented in Fig. 2, the methodology encompasses two primary phases: the web page processing phase, which determines whether a website is flagged or indexed, and the image analysis phase, where a deep learning Convolutional Neural Network (CNN) model is utilized for detecting violent content in images.

### A. Web Page Processing Phase

In this initial phase, the system seeks to determine the nature of the accessed website by checking its status in the database and providing real-time feedback to the user.

*1) Web page listener and data transmission:* We implement a lightweight web page listener utilizing a Puppeteer based Node.JS approach on the user's device. This allows us to access the data flowing into the device when a web page is being requested from the client side. This enables us to grab the text, images and videos embedded in the website. When a user accesses a web page, the listener captures the webpage link and transmits it to the server through an encrypted HTTPS connection. This ensures the secure transfer of user data while maintaining their privacy

and at the same time transferring the minimal amount of information required for further processing.

*2) Database check for flags or indexing:* The server hosts a relational database containing website information, including URLs, content flags, and indexing status. When the server receives the webpage link, it queries the database to determine if the website has been flagged for violent content or previously indexed in the past processing of the system. If such information is found to be previously flagged, the relevant data is relayed back to the user's device and appropriate actions are taken on the website view in the client application immediately. This approach's motive is to bypass the necessity to perform unnecessary processing of text, images and videos for every request and hence reducing the overall processing time, therefore trying to provide a seamless user experience.

*3) Web page blur/unblur:* If the database query confirms the presence of explicit content on the website, the user's device receives a notification instructing it to blur the explicit text, images, videos using the puppeteer module's capability. This user-friendly approach minimizes direct exposure to harmful content and maintains a safe browsing environment with quick processing.
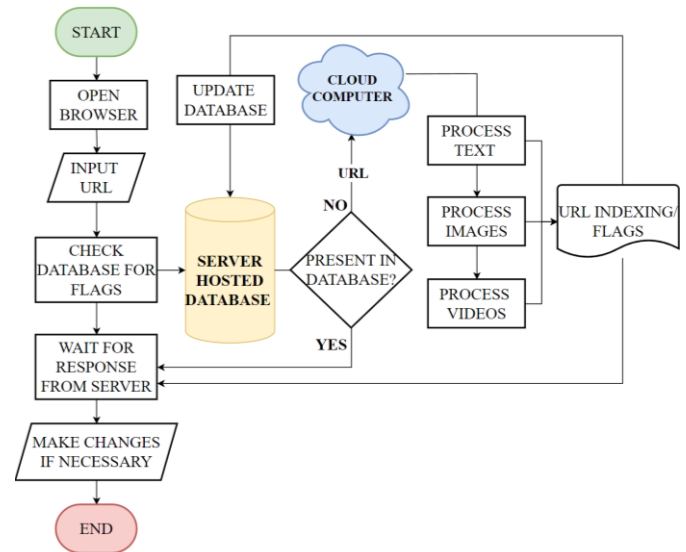


Fig. 2.   Flow diagram of the system.

### B. Data Analysis Phase

For websites without prior database information, the system initiates the data analysis phase, involving the application of a Natural Language Processing and deep learning CNN model to detect violent content in text and images/videos respectively.

*1) Cloud computing service setup:* To accommodate the computational demands of image analysis, we set up a cloud-based environment using Amazon Web Services (AWS). The cloud service is equipped with sufficient computational resources to handle multiple requests simultaneously, ensuring real-time responses. The major benefit of utilizing a cloud-based approach is the reduced load on the local user's system.

Hence the entire process will not affect the user's browsing experience, additionally the other background tasks running in the client-side systems will not be pulled out of its resource allocations for this purpose.

*2) Text processing:* The text is first extracted and analyzed using NLTK modules for sentiment analysis. The Sentiment Intensity Analyzer class of the NLTK's 'sentiment module' is utilized to score the text as polarity_scores. The score of all sentences is combined to form a compound score which is then classified as positive, neutral, and negative. Each sentence's polarity score is combined to generate a compound score, computed as in Eq. (1).

$$Compound\ Score = \sum Polarity\ Score\ of\ Sentences \quad (1)$$

This is done by using threshold values of -0.05 and +0.05 to categorize them as disturbing content or not as seen in Table III. Once it is determined as inappropriate, it halts the Data Analysis Phase and blurs the entire page.

TABLE III.    TEXT CLASSIFICATION

| Compound Score Range | Sentiment Classification |
|---|---|
| Less than -0.05 | Negative Sentiment |
| -0.05 to 0.05 | Neutral Sentiment |
| Greater than 0.05 | Positive Sentiment |

*3) Data preprocessing:* Images extracted from the accessed website's content, including frames from videos, are pre-processed to standardize dimensions and enhance the model's performance. The images are resized to 224x224 pixels irrespective to their original size or resolution or aspect ratio using Eq. (2).

$$Resized\ Image = Resize\ (Original, Target) \quad (2)$$

After resizing, the images are normalized to the [0, 1] range. This normalization process involves scaling the pixel values to fit within the specified range, which is vital for consistent input across the entire process.

$$Normalized\ Image = \frac{Resized\ Image}{255} \quad (3)$$

Eq. (3), where 255 represents the maximum pixel value in an 8-bit image. This allows that all inputs are maintained with consistency and is standard across the entire process.

*4) Deep learning CNN model:* For image analysis, we employ a Convoluted Neural Network model to analyze the images. To be specific, a pre-trained VGG16 CNN architecture, fine-tuned to detect violent content. The VGG16 model has demonstrated effectiveness in image classification tasks due to its deep 16-layer intensive ability to extract vital and meaningful information regarding the input images. By utilizing the VGG16 model to analyze individual frames extracted from videos, the system gains the ability to examine the video content frame by frame. This enables the detection of violent elements or patterns within the vide.

*5) Violent content detection:* Pre-processed images are fed through the CNN model to obtain predictions. The model outputs a probability score indicating the likelihood of the image containing violent content.

The program that analyzes the video consists of the modules and packages as seen in Table IV. Additionally, the parameters and variables assigned certain values to ensure the perfect working of this system is included in Table V.

TABLE IV.    MODULES AND PACKAGES

| Modules and Packages | Description |
|---|---|
| Asyncio | Employed for asynchronous programming, allowing efficient handling of WebSocket connections. |
| Websockets | Utilized to facilitate communication through WebSocket connections, crucial for real-time interaction. |
| OS | Enables essential file operations, such as handling paths and file removal. |
| PIL | Facilitates image processing tasks, aiding in resizing and other operations. |
| cv2 | Integral in reading and manipulating video frames, a key step in content analysis. |
| NumPy | Supports numerical operations, aiding in array manipulations and calculations. |

TABLE V.    PARAMETERS AND VARIABLES

| Parameters and Variables | Description |
|---|---|
| CLASSES_LIST | An array of class labels, specifically "Non-violence" and "Violence," used for classification. |
| model | The pre-trained CNN model loaded using Keras' **load_model** function, essential for content analysis. |
| SEQUENCE_LENGTH | A parameter determining the number of frames utilized for sequence analysis within the CNN model. |
| IMAGE_HEIGHT and IMAGE_WIDTH | Parameters dictating the dimensions to which frames are resized, ensuring consistency during analysis. |

To classify an image as violent or not, we set a threshold of 0.5 as in Table VI, based on validation results, above which an image is categorized as violent. The CNN model assigns a probability score $F_{violent}P_{violent}$ to each image. This score represents the likelihood of the image containing violent content. It can be expressed as in Eq. (4).

$$F_{violent}P_{violent} = CNN_{Model(Pre-processed\ Image)} \quad (4)$$

TABLE VI.    VIDEO CLASSIFICATION

| Probability Score | Classification |
|---|---|
| $P_{violent} > 0.5 P_{violent} > 0.5$ | Violent Content |
| $P_{violent} \leq 0.5 P_{violent} \leq 0.5$ | Non-Violent Content |

*6) Result transmission and database update:* The predictions from the CNN model are transmitted back to the server, which subsequently updates the database with the

violence detection result for the accessed website. This dynamic database enhancement ensures the continual improvement of the system's accuracy over time. This shows that the cloud is only communicating with the database and not with the client device directly. This method ensures that this process is not susceptible to external cyber-attack.

*7) User feedback and blurring:* The user's device receives the result of the violence detection process. If the result confirms the presence of explicit content, the user's device applies blurring to the corresponding images or videos, ensuring a safer browsing experience. In this case only the and all the non-violent images/videos stays unblurred, inferring that its just the specific violent content that are blurred. This is to provide the user with the best possible experience.

## V. RESULTS

To demonstrate the working of this system, local websites are utilized. This system is implemented by using a local cloud instance to run the Machine Learning programs that analyzes the text, images and videos. Additionally, a MongoDB database is fired-up to store the website information. All communications are made using web sockets to best emulate the real implementational results. In this implementation, the entire content is first blurred and eventually the content safe to be viewed are unblurred ensuring that no disturbing content is viewed in the small timeframe of computation. Multiple cases are considered to portray the working of the system. The result images depict the results in case of both when it's present and not present in the database.

### A. CASE 1: Non-Violent Text & No Videos in the Website

The text is classified as neutral and hence the website is unblurred as seen in Fig. 3.
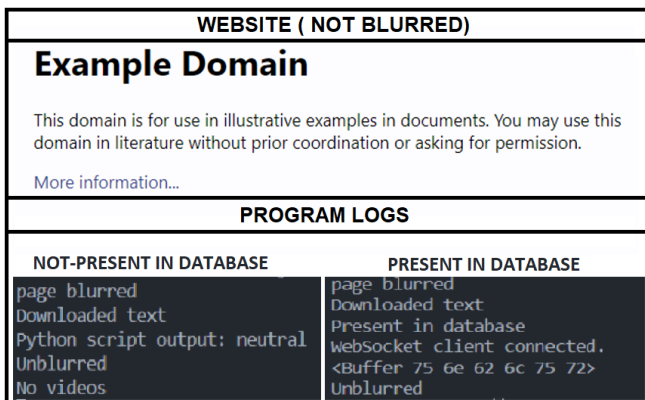


Fig. 3. Non-violent text and no videos in the website.

### B. CASE 2: Violent Text & (No/Violent/Non-Violent) Videos

The text is classified as negative and no other content is considered (videos). Hence the website is completely blurred as in Fig. 4.

### C. CASE 3: Non-Violent Text & Non-Violent Videos

The text is classified as neutral, the video is declared positive. Hence the website is unblurred as in Fig. 5.
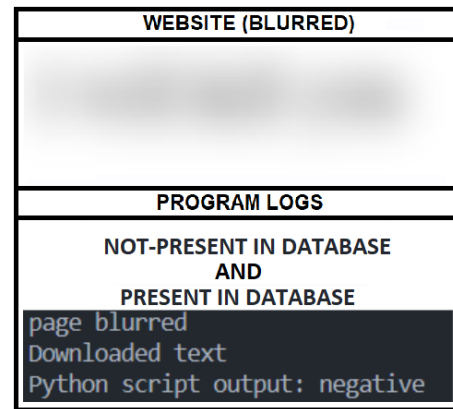


Fig. 4. Violent text and (no/violent/non-violent) videos.
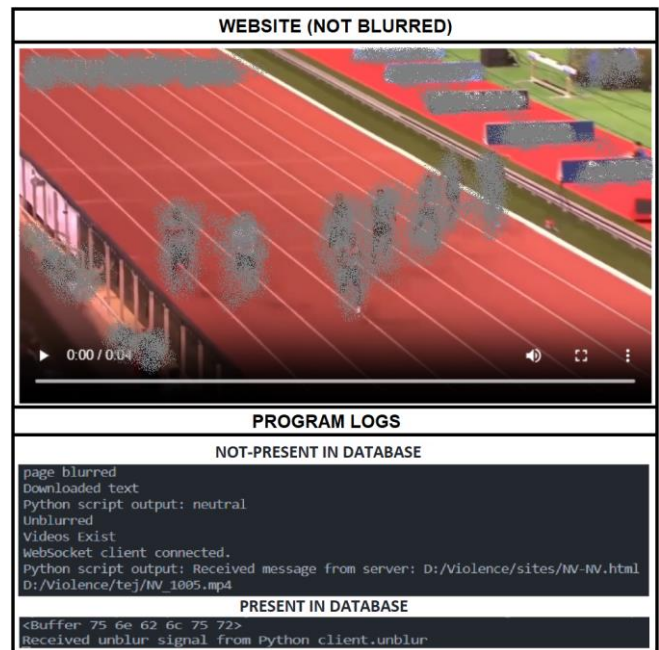


Fig. 5. Non-violent text and non-violent videos.

### D. CASE 4: Non-Violent Text & Violent Videos

The text is classified as neutral and video as negative. Hence the video portion of the website is only blurred as in Fig. 6.

The time taken to perform the various cases discussed is shown in Table VII. The data is visualized in the form of line graph. It can be easily noted that the Computation time is proportional to the length of the text or video being analyzed in the website. This noticed that, with the support of the database, we have continuous Time frame of two to three seconds. Except the case when the text in small and no video is present in the website, all other iterations require a considerably longer duration to process the content. Fig. 7 shows the ability to identify violent images quickly.

Even though the Fig. 8 shows 100% successful results in case of those four iterations, the model has an accuracy of 67% overall. Hence, utilizing this architecture, we are able to achieve exceptional speed and minimal computational load. Therefore, ensuring that the browser users are protected from

disturbing content, and without much interruption due to quick the shift between unblur and blur during the processing phase.
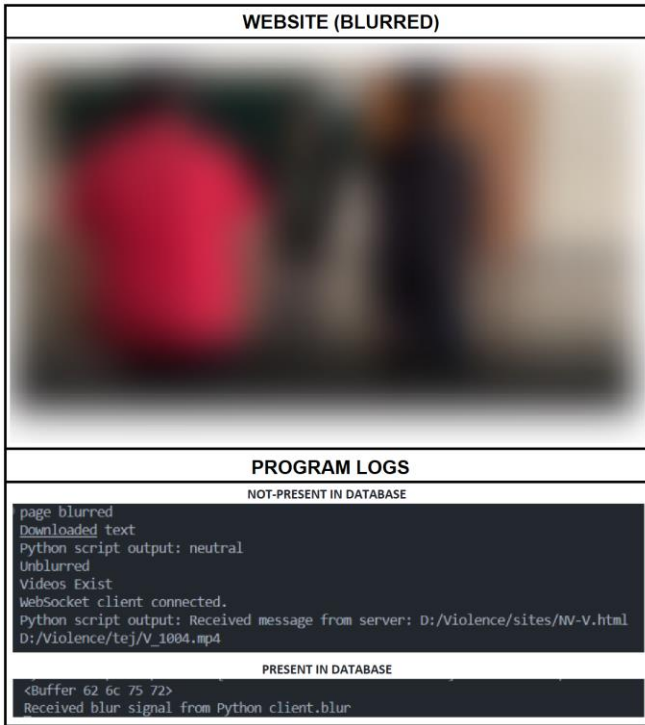


Fig. 6.  Non-violent text and violent videos.
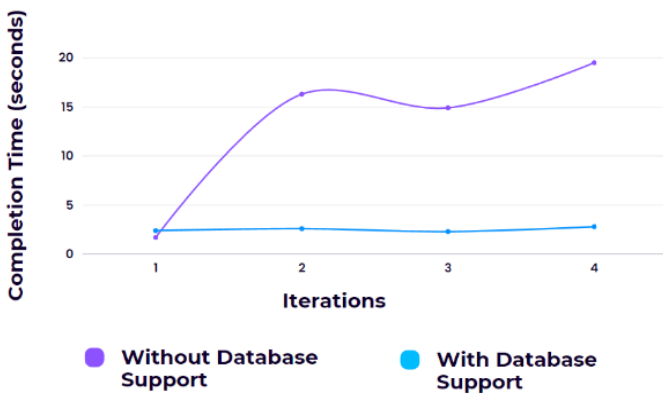


Fig. 7.  Comparing the implementation time with and without database.

TABLE VII.  PROCESSING TIME

| CASE | Text Processing Time | Video Completion Time | Total Time when not in database | Total time when URL is in the database | Probability Score |
|---|---|---|---|---|---|
| 1 | 1.7 sec | NULL | 1.7 sec | 2.4 sec | 0.2 |
| 2 | 1.3 sec | NULL/ 0 – 15 sec | 1.3 – 16.3 sec | 2.3 sec | 0.7 |
| 3 | 1.2 sec | 13.7 sec | 14.9 sec | 2.6 sec | 0.3 |
| 4 | 1.4 sec | 18.1 sec | 19.5 sec | 2.8 sec | 0.8 |
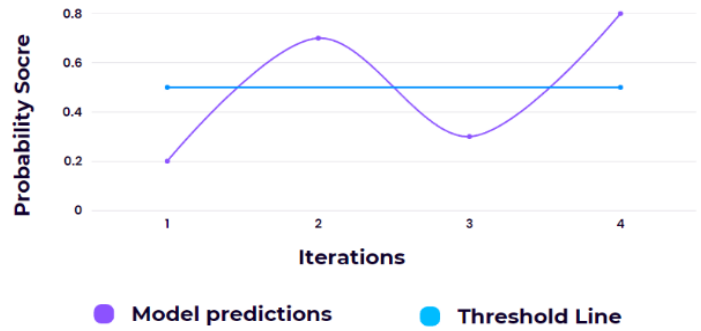


Fig. 8.  Detection performance comparison graph.

## VI.  CONCLUSION

Considering the evolution of internet in the modern society, it is the duty to protect its users' security and welfare, particularly in light of the skyrocketing risks posed by explicit and violent content. In this paper, we describe a complete method for improving web safety through real-time violence detection in text, photos and videos using machine learning methods, more specifically deep learning Convolutional Neural Networks (CNNs). By performing all processing intensive tasks in the Cloud, and storing the data in a database, as and when the analysis is completed for any website, we can achieve an improved user experience by not just completing all the necessary detection processes at a lower time frame, but also reduce the load on the user's local system. Machine learning models can be used to handle new explicit data with improvement and expansion of training datasets, making sure that the relevance of the system and ability to change in an online dynamic environment.

In conclusion, the effectiveness of utilizing machine learning to improve web safety is demonstrated by the suggested real-time violence detection system. Incorporating mainstream technologies such as Cloud Computing and Bigdata, we consistently achieved an accuracy of 67% over thousands of trials at a time. Moreover, the proposed system architecture achieves all this in under 2.5 seconds at its best-case condition, i.e. results stored in the database. Thus, we have made great progress towards fostering a safer digital environment for all users by fusing technology innovation with ethical considerations.

## REFERENCES

[1] Hidalgo, José María Gómez, Enrique Puertas Sanz, Francisco Carrero García, and Manuel De Buenaga Rodríguez. "Web content filtering." *Advances in computers* 76 (2009): 257-306.

[2] Gillespie, Tarleton. "Content moderation, AI, and the question of scale." *Big Data & Society* 7, no. 2 (2020): 2053951720943234.

[3] Lee, Pui Y., Siu C. Hui, and Alvis Cheuk M. Fong. "Neural networks for web content filtering." *IEEE intelligent systems* 17, no. 5 (2002): 48-57.

[4] Gorwa, Robert, Reuben Binns, and Christian Katzenbach. "Algorithmic content moderation: Technical and political challenges in the automation of platform governance." *Big Data & Society* 7, no. 1 (2020): 2053951719897945.

[5] Deniz, Oscar, Ismael Serrano, Gloria Bueno, and Tae-Kyun Kim. "Fast violence detection in video." In *2014 international conference on computer vision theory and applications (VISAPP)*, vol. 2, pp. 478-485. IEEE, 2014.

[6]    De Souza, Fillipe DM, Guillermo C. Chavez, Eduardo A. do Valle Jr, and Arnaldo de A. Araújo. "Violence detection in video using spatio-temporal features." In *2010 23rd SIBGRAPI Conference on Graphics, Patterns and Images*, pp. 224-230. IEEE, 2010.

[7]    Ramzan, Muhammad, Adnan Abid, Hikmat Ullah Khan, Shahid Mahmood Awan, Amina Ismail, Muzamil Ahmed, Mahwish Ilyas, and Ahsan Mahmood. "A review on state-of-the-art violence detection techniques." *IEEE Access* 7 (2019): 107560-107575.

[8]    Khan, Samee Ullah, Ijaz Ul Haq, Seungmin Rho, Sung Wook Baik, and Mi Young Lee. "Cover the violence: A novel Deep-Learning-Based approach towards violence-detection in movies." *Applied Sciences* 9, no. 22 (2019): 4963.

[9]    Sumon, Shakil Ahmed, Raihan Goni, Niyaz Bin Hashem, Tanzil Shahria, and Rashedur M. Rahman. "Violence detection by pretrained modules with different deep learning approaches." *Vietnam Journal of Computer Science* 7, no. 01 (2020): 19-40.

[10]   Wang, Pin, Peng Wang, and En Fan. "Violence detection and face recognition based on deep learning." *Pattern Recognition Letters* 142 (2021): 20-24.

[11]   Sernani, Paolo, Nicola Falcionelli, Selene Tomassini, Paolo Contardo, and Aldo Franco Dragoni. "Deep learning for automatic violence detection: Tests on the AIRTLab dataset." *IEEE Access* 9 (2021): 160580-160595.

[12]   Gu, Jiuxiang, Zhenhua Wang, Jason Kuen, Lianyang Ma, Amir Shahroudy, Bing Shuai, Ting Liu et al. "Recent advances in convolutional neural networks." *Pattern recognition* 77 (2018): 354-377.

[13]   Jing, Jin, Abdelsalam Sumi Helal, and Ahmed Elmagarmid. "Client-server computing in mobile environments." *ACM computing surveys (CSUR)* 31, no. 2 (1999): 117-157.

[14]   Kumar, Santosh. "A review on client-server based applications and research opportunity." *International Journal of Recent Scientific Research* 10, no. 7 (2019): 33857-3386.

[15]   Lewandowski, Scott M. "Frameworks for component-based client/server computing." *ACM Computing Surveys (CSUR)* 30, no. 1 (1998): 3-27.

[16]   Gupta, Bhumij, and M. P. Vani. "An overview of web sockets: The future of real-time communication." *Int. Res. J. Eng. Technol. IRJET* 5, no. 12 (2018).

[17]   Qveflander, Nikolai. "Pushing real time data usingHTML5 Web Sockets." Digitala Vetenskapliga Arkivet (2010).

[18]   Hormozi, Elham, Hadi Hormozi, Mohammad Kazem Akbari, and Morteza Sargolzai Javan. "Using of machine learning into cloud environment (a survey): managing and scheduling of resources in cloud systems." In *2012 Seventh International Conference on P2P, Parallel, Grid, Cloud and Internet Computing*, pp. 363-368. IEEE, 2012.

[19]   Pop, Daniel. "Machine learning and cloud computing: Survey of distributed and saas solutions." *arXiv preprint arXiv:1603.08767* (2016).

[20]   Islam, Tariqul, and Dakshnamoorthy Manivannan. "Predicting application failure in cloud: A machine learning approach." In *2017 IEEE International Conference on Cognitive Computing (ICCC)*, pp. 24-31. IEEE, 2017.

[21]   Wu, Dazhong, Connor Jennings, Janis Terpenny, and Soundar Kumara. "Cloud-based machine learning for predictive analytics: Tool wear prediction in milling." In 2016 IEEE International Conference on Big Data (Big Data), pp. 2062-2069. IEEE, 2016

[22]   Gongane, V.U., Munot, M.V. & Anuse, A.D. Detection and moderation of detrimental content on social media platforms: current status and future directions. Soc. Netw. Anal. Min. 12, 129 (2022). https://doi.org/10.1007/s13278-022-00951-3

[23]   P. Hajibabaee et al., "Offensive Language Detection on Social Media Based on Text Classification," 2022 IEEE 12th Annual Computing and Communication Workshop and Conference (CCWC), Las Vegas, NV, USA, 2022, pp. 0092-0098, doi: 10.1109/CCWC54503.2022.9720804.

[24]   Ali Qamar Bhatti, Muhammad Umer, Syed Hasan Adil, Mansoor Ebrahim, Daniyal Nawaz, Faizan Ahmed, "Explicit Content Detection System: An Approach towards a Safe and Ethical Environment", Applied Computational Intelligence and Soft Computing, vol. 2018, Article ID 1463546, 13 pages, 2018. https://doi.org/10.1155/2018/1463546

[25]   Devin Soni and Vivek K. Singh. 2018. See No Evil, Hear No Evil: Audio-Visual-Textual Cyberbullying Detection. Proc. ACM Hum.-Comput. Interact. 2, CSCW, Article 164 (November 2018), 26 pages. https://doi.org/10.1145/3274433

[26]   S. Parime and V. Suri, "Cyberbullying detection and prevention: Data mining and psychological perspective," 2014 International Conference on Circuits, Power and Computing Technologies [ICCPCT-2014], Nagercoil, India, 2014, pp. 1541-1547, doi: 10.1109/ICCPCT.2014.7054943.

# Detection of Autism Spectrum Disorder (ASD) from Natural Language Text using BERT and ChatGPT Models

Prasenjit Mukherjee[1], Gokul R. S.[2], Sourav Sadhukhan[3], Manish Godse[4], Baisakhi Chakraborty[5]

Dept. of Technology, Vodafone Intelligent Solutions, Pune, India[1, 2]
Dept. of Computer Science, Manipur International University, Manipur, India[1]
Dept. of Finance, Pune Institute of Business Management, Pune, India[3]
Dept. of IT, BizAmica Software, Pune, India[4]
Dept. of Computer Science and Engg, National Institute of Technology, Durgapur, India[5]

*Abstract*—**ASD may be caused by a combination of genetic and environmental factors, including gene mutations and exposure to toxins. People with ASD may also have trouble forming social relationships, have difficulty with communication and language, and struggle with sensory sensitivity. These difficulties can range from mild to severe and can affect a person's ability to interact with the world around them. Autism spectrum disorder (ASD) is a developmental disorder that affects people in different ways. But early detection of ASD in a child is a good option for parents to start corrective therapies and treatment. They can take action to reduce the ASD symptoms in their child. The proposed work is the detection of ASD in a child using a parent's dialog. The most popular Bert model and recent ChatGPT have been utilized to analyze the sentiment of each statement from parents for the detection of symptoms of ASD. The Bert model has been developed by the transformers which are the most popular in the natural language processing field whereas the ChatGPT model is a large language model (LLM). It is based on Reinforcement learning from human feedback (RLHF) that can able to generate the sentiment of the sentence, computer language codes, text paragraphs, etc. The sentiment analysis has been done on parents' dialog using the Bert model and ChatGPT model. The data has been prepared from various Autism groups on social sites and other resources on the internet. The data has been cleaned and prepared to train the Bert model and ChatGPT model. The Bert model is able to detect the sentiment of each sentence from parents. Any positive sentiment detection means parents should be aware of their children. The proposed model has given 83 percent accuracy according to the prepared data.**

*Keywords—BERT model; ChatGPT model; autism; machine learning; generative AI; autism detection*

## I. INTRODUCTION

Autism Spectrum Disorder (ASD) is a neurodevelopmental condition characterized by challenges in verbal communication, restricted interests, and repetitive behaviors as in [1]. The wide variability observed in individuals with ASD makes it difficult to establish universally applicable markers. As a result, there is a growing need for simpler and more accessible measurement techniques that can be routinely implemented for early detection purposes as in [2]. ASD may be caused by a combination of genetic and environmental

factors and is characterized by challenges with social skills, communication, and repetitive behaviors. Early diagnosis is important, as early intervention and treatment can improve outcomes and help those with ASD reach their full potential. Depending on the type of ASD, individuals may have difficulty with communication and social interaction, have repetitive behaviors, have difficulty with change, or have sensory sensitivities. Treatment plans are tailored to the individual and may include therapy, medication, and other services as in [3]. This is because autism is a complex disorder, and its symptoms can vary greatly from person to person. In addition, the symptoms of autism may not be obvious at first and can take some time to manifest. The 'spectrum' in ASD refers to the wide range of symptoms and their severity sometimes called Asperger's syndrome as in [4]. Thus, a comprehensive screening process is needed to properly detect autism. This means that the earlier the detection, the sooner the person can receive the necessary treatment and support, which can help to improve the quality of life for those with autism. In addition, early detection can also help to reduce the costs associated with the disorder, as treatments can be more effective when started early. This is because the signs and symptoms of autism can be very subtle in this age group and can be difficult to identify. Furthermore, the behavior of young children is constantly changing, which makes it even harder to accurately diagnose autism in this age group as in [5]. According to the autism report, the worldwide rate of increment of autism over the past decade is six children among 1000 children as in [6].

People with autism have difficulty in social interaction and communication and may have restricted and repetitive patterns of behavior, interests, or activities. Additionally, they may experience sensory sensitivities, have difficulty with transitions between activities, and have difficulty understanding abstract concepts as in [7]. Early detection of autism is important as it can help children to receive the necessary interventions and support to aid in their development. However, the lack of access to resources and the costs associated with screening tests make it difficult for families to get the help they need. While there is no cure for autism, there are effective treatments that focus on helping individuals with autism learn and develop skills and cope with

the challenges they face. These treatments may include behavior therapy, speech and language therapy, and occupational therapy. These symptoms can include difficulty with communication, sensory processing, and motor skills, as well as problems with memory, self-regulation, and social interactions. Additionally, these symptoms should interfere with the child's ability to function in home, school, and other social settings. Early diagnosis of ASD is a key to helping children reach their full potential and receiving the necessary treatment and interventions. Early diagnosis also allows for timely referral to other specialists and access to educational and behavioral therapies, which can help improve outcomes for children with ASD as in [8]. AI can analyze patterns and trends in large amounts of data more quickly and accurately than a human can. AI algorithms can be used to study genetic data, environmental factors, and symptom progression over time in order to identify or predict ASD. Higher dimensional data requires more sophisticated algorithms for analysis. Also, data from multiple sources can have different formats and structures, making it even more difficult to analyze. Therefore, artificial intelligence methods are needed to better analyze these types of data, which can be used for the prognosis and diagnosis of ASD as in [7]. Machine learning algorithms have the capability to analyze large amounts of data and identify patterns in the data that can be used to distinguish between individuals with ASD and those without as in [9]. Any machine learning model can be used but improvement of accuracy, precision, and recall will reduce the time complexity of the ASD diagnosis model as in [10]. Classification models are good to use for the detection of ASD of a person after improving the accuracy of the classification model as in [11]. By using these algorithms, physicians can better diagnose individuals with ASD and ensure they are receiving the proper treatment. By speeding up the autism diagnosis process, doctors and caregivers can quickly identify symptoms and provide the appropriate treatments that can help improve the quality of life for those with ASD as in [12].

The proposed research work detects the sentence that contains positive words that are pointing to ASD symptoms. The proposed system contains two machine learning models that are BERT model, and the ChatGPT model. A dataset has been prepared to train the BERT model. The dataset has been prepared from parents' dialogues who are actually parents of autistic children. Their experiences have been utilized to detect ASD symptoms. Parents of autistic children are spent most of their time with their children and their experience is the key to detecting ASD symptoms perfectly. The data has been collected from organizations that are working with autistic children. Some data has been collected from the social networks group. The dataset has been prepared according to the binary classification. A sentence containing positive words regarding autism sentence denotes true (1) and without positive words in a sentence denotes false (0). BERT model follows the most popular transformer architecture to do sentiment analysis where this model is trained with the prepared dataset that has been described in Section III. The ChatGPT model of OpenAI is another popular large language model in recent years. The architecture of this model uses reinforcement learning from human feedback (RLHF) architecture to solve many critical tasks. The example data

from the dataset has been sent to this model to understand the data structure and then new data send for predicting the sentiment for the detection of ASD symptoms. Both models are used to detect ASD symptoms. The detail of both models with the dataset has been discussed in Section III. The result of both models has been discussed in Section IV. The limitation and conclusion have been given in Sections V and VI respectively. Finally, this research paper ends with a future work.

## II. RELATED WORKS

Autism Spectrum Disorder (ASD) is a significant healthcare concern among children today, and it is considered one of the primary domains of interest in healthcare research. Artificial intelligence (AI) has become an increasingly popular approach for studying and treating ASD, and numerous studies have explored the use of AI in this field. In this section, we review some of the most important AI-based research on mental health issues, including ASD that have been conducted to date. These acoustic features are indicative of the underlying neurological mechanisms of the disorder. By analyzing these features, researchers can identify patterns that are unique to ASD speech and can identify individuals with autism at an early stage, which can then allow for early intervention and increased success in managing the disorder. These features are used to quantify the differences in speech production between children with ASD and those of a normal population. By analyzing these features, filter features formants (F1 to F5) researchers can identify potential differences in speech production between the two groups and better understand the impact of ASD on speech production. Significant changes in a few acoustic features are observed for ASD-affected speech as compared to normal speech. These changes indicate a difference in the production of speech sounds in individuals with ASD. This can help researchers understand the impact of ASD on speech production and suggest areas for further investigation. This is because the formants and dominant frequencies of the vowel /i/ are the most distinct between ASD and normal children. Additionally, the vowel 'I' is the most common vowel in speech and thus has the most data points to compare between groups. It provides a detailed analysis of how computer algorithms can be used to detect signs of autism in children. The authors provide evidence of how accurate these systems can be and how they can be used to aid in early diagnosis and intervention as in [13]. Early diagnosis of ASD is important in order to provide the necessary interventions and therapies to improve the quality of life for those affected. The development of easily implemented and effective screening methods can help to identify children with autism at an earlier age and provide them with the support they need. By using the Logistic Regression model, the researchers are able to capture the complex patterns of the dataset and accurately predict the outcome of ASD disease. Additionally, the algorithm will allow for rapid classification of the behaviors in the dataset, allowing for faster and more accurate predictions. These challenges include the need to ensure data privacy, to be able to trust the results of the AI system, to have the right infrastructure in place, and to ensure that the system is able to properly interpret the data. Additionally, healthcare

organizations must be able to adjust the system as new data becomes available and as the needs of the organization change as in [14]. What is often overlooked, however, is the importance of the quality of the interaction between the child and the caregiver. A supportive and responsive environment with frequent turns and back-and-forth exchanges between the adult and the child is essential for language development. We use observational methods to analyze the language used by caregivers in interactions with their children to see how well it predicts language development. The authors in [15] looked at the child's cognitive, social, and linguistic abilities to see if they are contributing factors to language development. Authors in [15] have used a longitudinal corpus of conversation data to measure how much caregivers repeat their children's words, syntax, and semantics, and whether this repetition is predictive of language development beyond other established predictors. Results: This is because by repeating and mirroring the child's language, the caregiver is providing the child with immediate feedback and reinforcement. This helps the child to better understand their language and helps them to develop their language skills in a more effective manner. Language acquisition is a process that relies on more than just memorization of information. It requires an interactive conversational model where the learner is engaged in meaningful dialogue with a teacher. Our open-source scripts provide a platform for researchers to explore this model in different languages and contexts as in [15]. NLP techniques are used to analyze the text and identify language patterns and emotions. This allows the system to identify users who may be experiencing depression, anxiety, or other mental health issues, and direct them to appropriate resources or suggest personalized interventions to help them cope with their issues. It also provides a comprehensive review of the literature on the various techniques and approaches used for data collection, processing, and analysis, as well as their advantages and limitations. Furthermore, this paper outlines the opportunities and challenges associated with the use of online data writing in mental health support and intervention. By using data from social media and other sources, researchers can detect certain patterns in language and behavior that can be used to identify individuals who may be in need of psychological assistance. Additionally, computational techniques can be used to label and diagnose mental health issues. Finally, through the use of machine learning and natural language processing, interventions can be generated and personalized for individuals in order to help them manage their mental health. This review seeks to provide a comprehensive overview of the existing literature in these fields and to identify gaps in the research and opportunities for future research and development. Additionally, it seeks to provide a common language to facilitate further collaborations between the different disciplines as in [16]. People with autism struggle with communication, interaction, and understanding social cues. They may be overly sensitive to sound, light, and other sensory inputs. They often have difficulty in understanding other people's feelings, and may also have difficulty forming relationships. They may also have unusual behavior patterns, such as repetitive movements or focusing on one topic for long periods of time. By using machine learning algorithms, doctors can identify potential markers of autism in a child at a much earlier stage than before. Early detection of autism can allow parents to seek out treatments and therapies that may help reduce the severity of autism in their children. We will use data from clinical studies, medical records, and other sources to develop a model that can accurately predict the outcome of autism diagnosis in children. We will analyze the data to identify patterns and develop an algorithm that can be used to predict outcomes. We will also evaluate existing machine learning models to determine which ones may be suitable for our proposed work. This method allows us to compare the results of the two groups of patients and look for any correlations between the data and how it may impact the diagnosis and treatment of future patients. Additionally, this approach can help us to identify any potential trends in the data which could further inform our understanding of the condition. By using LR, NB, DT, and KNN algorithms, we can apply different techniques to the data set, such as feature engineering and feature selection. This will help to ensure that the most important factors influencing the diagnosis of autism is being taken into account and that the predictive models are accurate and reliable as in [17]. The ASD QA dataset provides a unique challenge for MRC models, as it requires them to understand the context of the reading passage in order to correctly identify the answer. It is particularly difficult because the answers are not always straightforward and may require some inference or deduction. The dataset was created by selecting a set of questions from the ARC dataset and extracting the corresponding answer segments from passages in Wikipedia. The questions are generated from the passages using a variety of techniques. By adding these questions, we can evaluate the system's ability to identify and classify unanswerable questions. This is important to ensure that the system is not simply guessing, but rather, it is using the contextual information in the reading passage to accurately identify answerable and unanswerable questions. Each answer contains also positional tags (start and end) denoting the numerical positions of the first and last symbols of the answer span in a reading passage. 5% of the questions in ASD QA are unanswerable, which means that corresponding reading passages do not contain any answers to them. This split was chosen so that the model could be trained on the majority of the data, tested and validated on a smaller portion of the data to ensure accuracy, and then tested on an unseen portion of the data to ensure that it is generalizing correctly. Byte pair encoding is a method of compressing words into smaller units of meaning, which reduces the overall vocabulary size and makes it easier for the models to learn. This is beneficial for both types of models, as it reduces the amount of noise in the data, allowing for more accurate predictions as in [18]. One possible risk factor that has been identified is the presence of co-occurring mental health conditions, such as depression, anxiety, and obsessive-compulsive disorder. These conditions can be exacerbated in young people with ASD due to the difficulties they face in forming social relationships, communicating effectively, and coping with sensory overload. EHRs can provide a large amount of data, but they are often not standardized, making it difficult to accurately extract the data needed to create a valid cohort. Developing systems to accurately extract and organize the data would allow researchers to better understand the

relationship between ASD and suicide risk. The systematic approach utilizes NLP to identify the suicidal language in the EHR corpus and determine if the language is positive or negative. The performance of the classification tool is then evaluated on a subset of 500 patients. The precision score indicates the proportion of relevant results to the total relevant results retrieved, and the recall score measures the proportion of relevant results retrieved to the total amount of relevant results. The F1 score combines these two scores, providing a single value that is indicative of the system's overall performance. In this case, all of these scores were very high, indicating that the NLP classification tool was highly accurate in recognizing positive suicidality. The application has been validated against existing research and has been found to be effective in identifying potential risk factors for suicidality among individuals with ASD. It has also been found to be useful in predicting suicide risk and providing automated surveillance within clinical settings as in [19]. MRI imaging modalities have the capability to detect subtle brain abnormalities that are associated with ASD, such as changes in the brain's structure, connectivity, and even in its chemistry. This makes it an invaluable tool for diagnosing and monitoring ASD. fMRI uses magnetic fields and radio waves to measure blood flow in the brain and identify any abnormalities or discrepancies in brain activity. sMRI uses high-resolution images to map the structure of the brain and detect any abnormalities in the brain anatomy. These two modalities work together to help clinicians diagnose ASD with greater precision. These systems use AI to analyze brain images, such as MRI and fMRI scans, to assess an individual's brain structure and connectivity. The AI algorithms can detect subtle differences in brain structures which can be used to diagnose ASD more accurately and quickly by specialists. ML algorithms are used to analyze the image data, identify the relevant features, and detect any abnormalities that could be indicative of ASD. DL applications are used to further analyze the data and identify patterns that may be indicative of ASD. This allows for more accurate and reliable diagnoses. Deep Learning (DL) techniques employ large datasets of MRI images and AI algorithms to create models that can detect patterns in the images that are associated with ASD. These

models can then be used to automate the diagnosis of ASD and provide more accurate and timely results. We compare the accuracy and training times of ML and DL models to show that DL models can learn faster and achieve higher accuracy. We also discuss the importance of feature selection and data pre-processing in improving the accuracy of the models. Finally, we suggest the potential of combining AI techniques with MRI neuroimaging to detect ASDs as in [20]. Diagnosis of ADHD is typically based on a combination of self-reported symptoms, observations by parents and teachers, and psychological tests. Therefore, it can be difficult to accurately diagnose ADHD since there is no concrete, medical evidence to support a diagnosis. The proposed method was tested on a publicly available ADHD-200 dataset, which showed that 4-D CNN had better performance than traditional methods in terms of accuracy, specificity, and sensitivity. Furthermore, it was also demonstrated that 4-D CNN could effectively detect subtle differences in RS-fMRI data between ADHD and healthy individuals. These models take advantage of the spatiotemporal information of the RS-fMRI images to extract useful information about the brain. For example, the feature pooling model can be used to detect patterns in the data that are consistent across multiple time frames, while the LSTM model can be used to analyze the temporal dynamics of the data. The spatiotemporal convolution model can be used to identify spatial structures in the data. The approach is designed to reduce the computational cost of training deep learning models on fMRI data. By breaking the fMRI frames into shorter pieces with a fixed stride, the data can be processed more quickly and efficiently. The results of the evaluations demonstrate that our 4-D CNN method is more effective at accurately diagnosing ADHD than traditional methods. This method can be used to create a powerful and efficient tool that can be used to accurately diagnose ADHD and provide clinicians with the information they need to make informed decisions as in [21]. A comparative analysis has been done with proposed models and some similar machine learning models that are able to detect mental disorders. The proposed analysis has been described in Table I. This table contains 'Models', 'Description', 'Dataset', 'Accuracy', and 'Remarks' as attributes.

TABLE I.    COMPARATIVE ANALYSIS BETWEEN PROPOSED MACHINE LEARNING MODELS AND SIMILAR MACHINE LEARNING MODELS BASED ON MENTAL DISORDER DETECTION

| Sl.No. | Models | Description | Dataset | Accuracy | Remarks |
|---|---|---|---|---|---|
| | | **Similar Type Machine Learning Models in Mental Disorders** | | | |
| 1 | Logistic Regression [14] | The Logistic Regression model has been used in the diagnosis and detection of ASD. | Screening data of a group of toddlers related to autism | 100% | The proposed dataset has been prepared with 1054 instances and 18 attributes to train and test the model to detect ASD. |
| 2 | Logistic Regression(LR), Naïve Bayes(NB), Decision Tree(DT), K-Nearest Neighbour(KNN) [17] | These models are used to predict ASD using ASD patients and normal patients' data. | The dataset contains data related to normal patients and ASD patients. | 99.37%, 96.59%, 100%, and 97.73% | The dataset contains a large number of irrelevant and missing data. Many pre-processing techniques have been applied to clean datasets. |
| 3 | 4-D CNN [21] | This deep learning model training is based on the fMRI frames dataset to detect ADHD automatically. | This dataset consists of the fMRI frames data. | 71.3% | The proposed deep learning model 4d-CNN is able to detect ADHD using resting-state functional magnetic resonance imaging (rs-fMRI). |

| 4 | Random Forest, Ridge, SVM [20] | ,These models use sMRI and fMRI neuroimaging data to detect ASD. | NDAR and ABIDE datasets have been used that are containing sMRI and fMRI neuroimaging data. | 72%, 71%, and 75.3 | Software tools are needed to pre-process these kinds of MRI data. The brain extraction tools (BET), FMRIB software libraries (FSL), statistical parametric mapping (SPM), and Free Surfer are used to preprocess MRI data. |
|---|---|---|---|---|---|
| 5 | KNN, RF, SVM [20] | These models use sMRI and fMRI neuroimaging data to detect ASD. | NDAR and ABIDE datasets have been used that are containing sMRI and fMRI neuroimaging data. | 81%, 81%, and 78.63% | Software tools are needed to pre-process this kind of MRI data. The brain extraction tools (BET), FMRIB software libraries (FSL), statistical parametric mapping (SPM), and Free Surfer are used to preprocess MRI data. |
| 6 | Logistic Regression, Random Forest [20] | These models use sMRI and fMRI neuroimaging data to detect ASD. | UCI dataset has been used which is containing sMRI and fMRI neuroimaging data. | 97.54% and 100% | Software tools are needed to pre-process this kind of MRI data. The brain extraction tools (BET), FMRIB software libraries (FSL), statistical parametric mapping (SPM), and Free Surfer are used to preprocess MRI data. |
| 7 | Siamese Verification Model and GERSVMC [20] | These models use sMRI and fMRI neuroimaging data to detect ASD. | NDAR and ABIDE datasets have been used that are containing sMRI and fMRI neuroimaging data. | 87% and 96.8% | Software tools are needed to pre-process this kind of MRI data. The brain extraction tools (BET), FMRIB software libraries (FSL), statistical parametric mapping (SPM), and Free Surfer are used to preprocess MRI data. |
| **Proposed Models in Mental Disorder (Autism Spectrum Disorder)** | | | | | |
| 8 | Proposed BERT Model | The BERT model has been proposed to predict positive ASD symptoms from parents' dialogue. | Parents' Dialogues of Autistic Children in text format from SAHAS-Durgapur, India, and Social Sites. | 83% | The data has been collected in text form. The parents' dialogues about their autistic children are very useful because they shared their experiences and thoughts about their autistic children. A parent of an autistic child is the best source to understand the ASD symptoms patterns. |
| 9 | Proposed OpenAI ChatGPT Model | ChatGPT model has been used to predict positive ASD symptoms from parents' dialogue. | Parents' Dialogues of Autistic Children in text format from SAHAS-Durgapur, India, and Social Sites. | Fine-Tuned and Pre-trained model of OpenAI with High Accuracy | The data has been collected in text form. The parents' dialogues about their autistic children are very useful because they shared their experiences and thoughts about their autistic children. A parent of an autistic child is the best source to understand the ASD symptoms patterns. |

## III. ARCHITECTURE

Two advanced machine learning models have been used to identify ASD symptoms from parents' dialogues. BERT has been used as the first model to detect the symptoms from the parents' dialogue whereas the ChatGPT model has been used as a second model to detect ASD symptoms from the given dataset. KNN and Random forest are the last two classifiers that are also used to identify ASD symptoms from a given dataset.

### A. Dataset

The dataset is prepared by analyzing parents' dialogues in which they described their thoughts and experiences related to their own child with Autism Spectrum Disorder (ASD). These dialogues were obtained from various social networks and organizations where children with special needs receive therapies for communication, speech, and behavior. Table II provides a few examples of these dialogues. Parents' dialogues are a valuable source of data for identifying all possible symptoms of ASD. We used these dialogues to create a dataset for training and testing our proposed machine-learning models.

The dataset was meticulously curated from the content presented in Table II, with a thorough examination of each sentence to ascertain its relevance as a potential symptom of Autism Spectrum Disorder (ASD). It is important to note that the identification of ASD symptoms is not constrained by a fixed set of criteria, allowing for a comprehensive exploration of various indicators. To enhance the dataset and bolster the accuracy of machine learning models, a promising avenue could involve the augmentation of dialogues from parents who have firsthand experience with autistic children. This approach not only facilitates the discovery of additional symptoms but also offers a valuable opportunity to refine machine learning algorithms. Table III provides a glimpse of the dataset, offering illustrative examples of the data's composition.

Table III provides a comprehensive overview of the dataset structure proposed in this research endeavor. The dataset comprises three distinct columns: Serial Number, Comments, and Sentiment. To compile this dataset, textual excerpts were extracted from parents' dialogues, wherein each sentence underwent a rigorous evaluation to determine its association with Autism Spectrum Disorder (ASD) symptoms. Sentences that were indicative of ASD symptoms were categorized with a label of 1 (representing true), while those not exhibiting such symptoms were assigned a label of 0 (indicating false). Referring to Table III, it becomes evident that the Comments column, under serial numbers 1, 3, and 4, highlights sentences bearing true ASD symptoms, while serial numbers 2 and 5 correspond to sentences devoid of ASD symptoms. This meticulously curated ASD symptom-based dataset is now poised for the training of advanced machine learning models such as BERT and ChatGPT, holding promise

for enhancing our understanding and analysis of ASD-related linguistic cues.

TABLE II. EXAMPLE OF PARENTS' DIALOGUES

| Sl. No. | Parents' Dialogues |
|---|---|
| 1. | My son is 20, has autism, high functioning. Drives, works but still struggles with socializing like most. eye contact can be minimal, talking is minimal ( no small talk) He is being bullied now in the work place to the point his ptsd from childhood bullying is affecting him. I try to empower him but he is scared of getting Hit by his coworker |
| 2. | He cries every night and every day about going to nursery. Unfortunately the past few weeks have been awful, he is very upset about going to nursery again and is now asking if he is going the next day at bath time and then when he wakes up in the morning he screams and cries and has to be physically dressed and put in the car. |
| 3. | I am new here I just want to ask about any private speech and language therapist in ENGLAND at Oldham, my 2 years baby is not talking yet, sometime not responding. I am very worried for my son. Please help me for guiding. |
| 4. | My daughter-in-law spoils him let's him have and do whatever he wants. I'm sure it's because they don't want to hear his screams Now she's temporary out of the picture. Her oldest son age 12 opens the fridge and lets him grab whatever because mom let him. I put a stop to it because food is going to waste within a day it makes it hard when the one year old wants milk and there's none because it gets spoiled. Am I wrong in not letting the 5 year old not have his way? |
| 5. | My 9 year old little man was recently diagnosed with Autism and waiting for further appointments for ADHD. Does anyone else's child suffer with bad meltdowns and constantly angry and stressed? |

TABLE III. EXAMPLE DATA IN THE PROPOSED DATASET

| Sl. No. | Comments | Sentiment |
|---|---|---|
| 1. | He is playing with toys and spin wheels every time | 1 |
| 2. | Please help me understand autism because my son is 4 years old now | 0 |
| 3. | My little girl is 3 years old but she is able to speak. | 1 |
| 4. | She mumbles but can speak any proper word. | 1 |
| 5. | I was really surprised when she came home and asked her mom about me. | 0 |

TABLE IV. LIST OF LABELS WITH ASD PROBLEMS

| Sl. No. | Label | ASD Problems |
|---|---|---|
| 1. | 1 | Speech Problem |
| 2. | 2 | Sensory Problem |
| 3. | 3 | Behaviour Problem |
| 4. | 4 | Special Education |
| 5. | 5 | Social Interaction |
| 6. | 6 | Eye Contact |
| 7. | 7 | Cognitive Behaviour |
| 8. | 8 | Hyper Active Problem |
| 9. | 9 | Child Psychological Problem |
| 10. | 10 | Attention Problem |

Table IV serves as a reference for the association between ASD problems and their respective labels. Each label in Table

IV represents a specific ASD problem, with Label 1 indicating "Speech Problem," Label 2 denoting "Sensory" issues, and Label 3 representing "Behavior" problems. Additionally, Table IV includes labels for other ASD problems. Once the sentiment of a sentence related to ASD symptoms is predicted, the proposed system utilizes Table IV to determine the corresponding label associated with the identified problem. In the system flow, when a sentence is classified as positive (1), it becomes the input for the Spacy cosine similarity model. This model compares the positive sentence with the dataset presented in Table V, which contains numerous positive sentences accompanied by their respective labels. Each label in Table V corresponds to an ASD problem as defined in Table IV. As described in the Proposed System Flow section, the cosine similarity model performs a similarity check between the predicted positive sentences and the sentences within the dataset. This process aims to identify the sentence in the dataset that is most similar to the input sentence. The label associated with this highly similar sentence is then selected by the system. By utilizing the information from Table IV and Table V, the proposed system matches positive sentences, which indicate ASD symptoms, with their respective labels. This matching process allows for the identification of specific ASD problems based on the BERT cosine similarity scores calculated by the system.

TABLE V. DATASET FOR COSINE SIMILARITY CHECK

| Sl. No. | Positive Sentences | Label |
|---|---|---|
| 1. | I am unable to demonstrate potty training to him during the daytime when his father is at work. | 7 |
| 2. | He primarily mumbles and doesn't use coherent words. | 1 |
| 3. | When I beckon him, he doesn't respond by coming to me. | 10 |
| 4. | He requires visual cues to comprehend my communication. | 6 |
| 5. | Her frustration deeply affects me and I'm hoping to hear some success stories. | 9 |

In the subsequent sections, we have detailed each model, including the algorithm employed in its implementation. This dataset served as the foundational training data for these models, and the outcomes of each model have been extensively examined and deliberated upon in the Results and Discussion section.

*B. BERT Deep Learning Model*

BERT is a deep learning model for natural language processing that helps to understand the meaning of a text or sentence according to the context. The BERT model is trained with the Wikipedia dataset and it can be fine-tuned for better accuracy. BERT stands for Bidirectional Encoder Representations from Transformers which means the entire model is based on transformers which is itself a deep learning model. Each output is well connected with each input in this deep learning model and weights are calculated dynamically according to the input-output connection. BERT has the capability of a Masked Language Model (MLM) where a word from the sentence is hidden at the training time and later

this model predicts the hidden word based on the context. BERT is dependent on the self-attention mechanism which is possible for the bidirectional transformers. The encoder and decoder are connected in the form of sequence to sequence model inside the transformer. The mathematical representation is-

$$Attention\,(A, B, C) = softmax\,(AB^T / \sqrt{d_b})\,C$$

A, B, and C are the embedding vector that is transformed by a weight matrix inside the transformer and training of transformers means finding weight matrices. The transformer model becomes a language model when weight matrices are learned. The BERT model contains a set of rules to represent the input text. Input text converts into the embedding parts which is a combination of three embeddings. According to Fig. 1, the token embeddings will be created from the tokenization of the input text. The segment embedding is needed to understand unique embedding from the given two sentences like "my baby is Autistic, she likes to play". The model can understand better the sentence to distinguish between them. The BERT model uses positional embedding which helps to understand the position of each word in a sentence. Summations of These three embeddings are representing the input inside the BERT model.
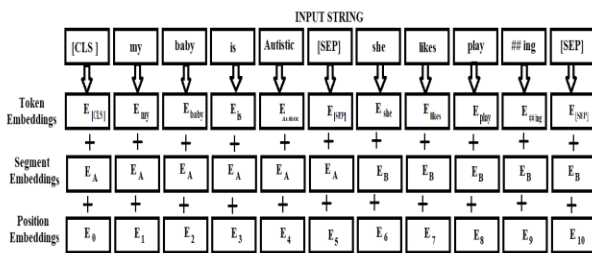


Fig. 1. Input text embedding in BERT model.

Fig, 2 of the Transformer architecture in [22] shows that it has two parts. The first part is Encoder and the second part is Decoder. After the conversion of input text to input embeddings, Encoder starts to handle input embeddings. The Encoder block contains two layers. The first layer is the Multi-Head Attention layer which is connected to the second layer named Feed Forward Neural Network. The encoder block encoded the data and sends it to the Decoder block where the Multi-Head Attention layer and Feed Forward Neural Network are connected but one extra layer is also connected which is Masked Multi-Head Attention. Different masked are handled by this layer. The proposed autism-related dataset has been applied in the BERT model to understand the sentence sentiment for identifying positive and negative symptoms of an autistic child.

The proposed system using the BERT model reads data from the proposed prepared dataset. Some NLP-related tasks have been done that are tokenization and embedding. The embedding and labeled data will be split for creation train and test data for the BERT model. The training data will be used for model training purposes as well as testing data will be used for the model performance purpose. The algorithm of the proposed system using BERT model has been given below:
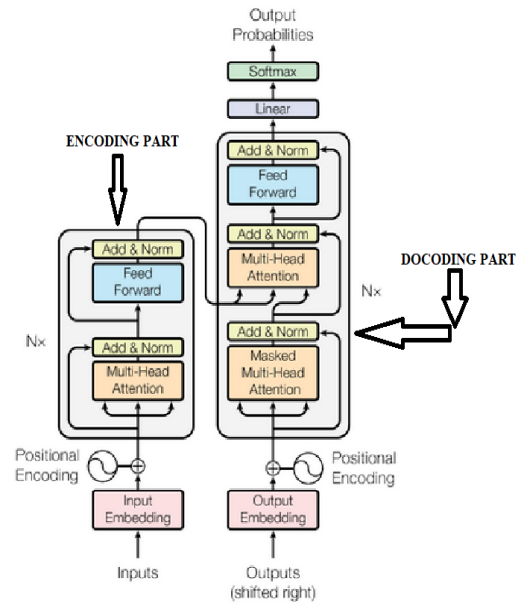


Fig. 2. The architecture of the transformer [22].

*Proposed BERT Algorithm:*
*Pseudo Code:*
*Step 1: Read data from CSV file.*
   *Step 2: X=data from csv*

      $x_l = [a_1, a_2, a_3, a_4, a_5, \ldots \ldots a_n]$ *is a user text column inside the dataset.*

      $y_l = [r_1, r_2, r_3, r_4, r_5, \ldots \ldots r_n]$ *is a label data column inside the dataset*
*Step 3: BERT model name selection.*
*// Set BERT model name*
*MODEL_NAME = 'bert-base-cased'*
*// Build a BERT based tokenizer*
*tokenizer = BertTokenizer.from_pretrained(MODEL_NAME)*
*Step 4: Train and test data creation.*
*df_train, df_test = train_test_split(X, test_size=0.2, random_state=RANDOM_SEED)*
*df_val, df_test = train_test_split(df_test, test_size=0.5, random_state=RANDOM_SEED)*
*def create_data_loader(df, tokenizer, max_len, batch_size):*
  *ds = GPReviewDataset(*
    *reviews=df.Comments.to_numpy(),*
    *targets=df.Sentiment.to_numpy(),*
    *tokenizer=tokenizer,*
    *max_len=max_len*
  *)*
  *return DataLoader(*
    *ds,*
    *batch_size=batch_size,*
    *num_workers=0*
  *)*

*// Create train, test and val data loaders*
*BATCH_SIZE = 16*

```
train_data_loader = create_data_loader(df_train, tokenizer,
MAX_LEN, BATCH_SIZE)
val_data_loader = create_data_loader(df_val, tokenizer,
MAX_LEN, BATCH_SIZE)
test_data_loader = create_data_loader(df_test, tokenizer,
MAX_LEN, BATCH_SIZE)
```

*Step 5: Create BERT model for sentiment analysis.*
```
bert_model = BertModel.from_pretrained(MODEL_NAME)
```

```
# Build the Sentiment Classifier class
class SentimentClassifier(nn.Module):

   // Constructor class
   def __init__(self, n_classes):
      super(SentimentClassifier, self).__init__()
      self.bert = BertModel.from_pretrained(MODEL_NAME)
      self.drop = nn.Dropout(p=0.3)
      self.out     =      nn.Linear(self.bert.config.hidden_size,
n_classes)

   // Forward propagaion class
   def forward(self, input_ids, attention_mask):
      _, pooled_output = self.bert(
         input_ids=input_ids,
         attention_mask=attention_mask,
         return_dict=False

      )
      // dropout layer addition
      output = self.drop(pooled_output)
      return self.out(output)
```

```
// Instantiate the model and move to classifier
model = SentimentClassifier(len(class_names))
```

The result of this proposed algorithm has been discussed in the Result and Discussion section.

### C. ChatGPT (Large Language Model)

Today, ChatGPT has taken a very strong position to handle natural language processing tasks. ChatGPT model is an advancement of Large Language Model (LLM). ChatGPT model has been developed using reinforcement learning from human feedback (RLHF). RLHF is a reinforcement learning which is a machine learning algorithm where an agent learns everything from the environment using policy. According to Fig. 3, the agent may take action ($A_t$) according to the policy which affects the environment where the agent is present. According to Fig. 4, the agent may take action ($A_t$) according to the policy which affects the environment where the agent is present. According to this action taken, a new state ($S_t$) is generated and it returns a reward ($R_t$). Rewards are nothing but the feedback signals which indicated the reinforcement learning agent to tune action policy. In the next step, The RL agent modifies the policy to take sequences of actions when it goes through training episodes and as a result, it maximizes the rewards.
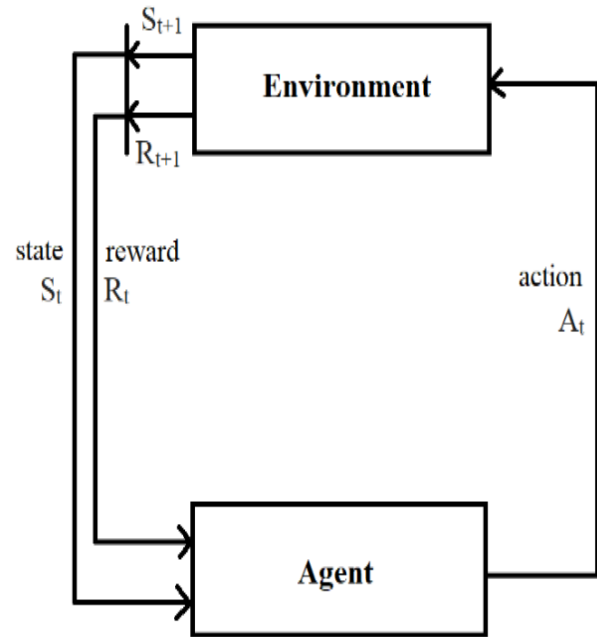


Fig. 3. Reinforcement learning basic diagram.

ChatGPT (GPT stands for Generative Pre-trained Transformer) is a large language model (LLM) developed by OpenAI. ChatGPT is trained on a massive amount of text and code data from the internet. The dataset includes text from books, articles, websites, and code from GitHub repositories. A brief description has been given according to Fig. 4.

*1)* The training process for ChatGPT involves several stages. First, the model is initialized with a data transformation stage where tokenization and vectorization methods are used to prepare text data for training. These are important steps because they help the ChatGPT model to understand the meaning of the text and generate text that is both coherent and grammatically correct.

*2)* The tokenization stage involves breaking down text into smaller units, called tokens. Tokens can be individual words, phrases, or even characters. The type of tokenization used for ChatGPT is called WordPiece tokenization. In this tokenization method text breaks down into tokens that are still meaningful, even if they are not individual words. For example, the word "running" would be broken down into the tokens "run" and "ing".

*3)* After completion of tokenization, it is converted into vectors. Vectors are mathematical objects that represent the meaning of a token. The vectors for each token are learned during the training process. The vectors are then used by the CHATGPT model to generate text, translate languages, and perform other tasks.

*4)* Once the text data is vectorized then, it is trained using a transformer Model (unsupervised learning) which is a neural network architecture that has been shown to be very effective for natural language processing tasks. It consists of encoder and decoder layers. The encoder layers take in a sequence of

text tokens and transform them into a sequence of hidden representations. The decoder layers then use these hidden representations to generate a new sequence of text tokens. to process the new sequence of text tokens distributed learning is a technique used. It involves splitting the model across multiple machines, each of which is responsible for training a subset of the model's parameters. This allows the model to be trained more quickly and efficiently than if it were trained on a single machine.

*5)* In distributed learning technique, two methods are involved, data parallelism and model parallelism. In data parallelism, the training data is split across the machines, and each machine trains its own copy of the model. In model parallelism, the model's parameters are split across the machines, and each machine trains its own subset of the parameters. ChatGPT used this distributed learning technic to train massive datasets of text and code, which allowed it to achieve the best performance on a variety of natural language processing tasks. It uses an Azure-based supercomputing platform to process the data and models.

*6)* After completion of model training, it can be fine-tuned for specific natural language processing tasks, such as language translation, text summarization, and question answering. Fine-tuning involves training the model on a smaller amount of task-specific data, which allows it to learn to perform the task more accurately and efficiently.

*7)* After completion of model training, it can be fine-tuned for specific natural language processing tasks, such as

language translation, text summarization, and question answering. Fine-tuning involves training the model on a smaller amount of task-specific data, which allows it to learn to perform the task more accurately and efficiently.

The Reinforcement learning from human feedback helps to enhance the training process of RL agents where humans are also included. An architectural diagram of LLM has been given in Fig. 5. According to Fig. 5, RLHF in language models consists in three phases where the first phase is related to the huge data training because LLM requires a huge amount of data to be trained. The LLM is pre-trained using unsupervised learning and it creates coherent outputs. Some of the output may be aligned or not aligned according to the goal of users. In the second phase, a reward model has been created where another LLM model uses the generated text from the main model to produce quality scores. The second LLM has been modified for scalar value instead of a sequence of text tokens. A dataset of LLM-generated text labeled will be generated for quality. A prompt will be given to the main LLM to generate several outputs. The human evaluator will intervene here to evaluate generated output on the basis of good and bad. In the third phase, the main LLM is an RL agent where it takes several prompts from a generated text and training set. The output of this LLM model is passed to the reward model that provides the score and aligns with the human evaluator. Finally reward model creates output according to the higher score. ChatGPT uses this RLHF framework to handle a large number of natural language queries. The engineers of OpenAI have modified the model for fine-tuning on pre-trained GPT-3.5.
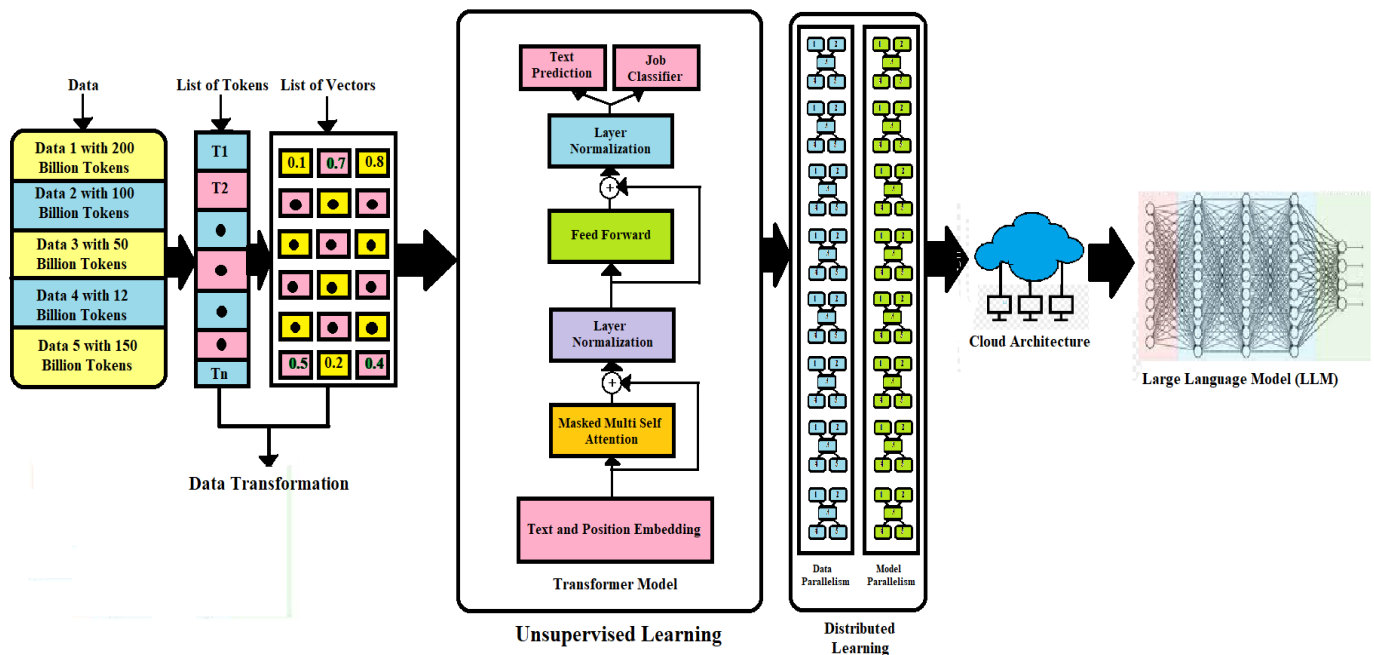


Fig. 4. ChatGPT model architecture.
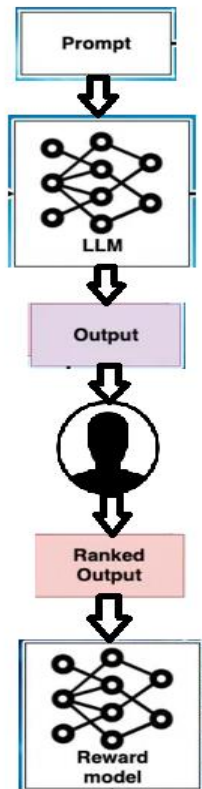
Fig. 5. Large language model diagram.



Fig. 6. ChatGPT request-response basic diagram.

According to Fig. 6, the pre-trained ChatGPT model accepts example data to understand the structure of the data. The dataset is containing structured data. ChatGPT needs example structured data to understand the pattern for response

generation but there is a limitation of sending example data to the ChatGPT. ChatGPT reads data as a token and within this token limitation example data has to be sent. Now, ChatGPT is ready to generate responses to new requests. The algorithm of the proposed sentiment analysis using the ChatGPT model has been described below.

*Proposed ChatGPT algorithm:*
*Pseudo code:*
*Step 1: Initialize API key in a variable*
*import openai as ai*
*ai.api_key='API_Key'*
*Step 2: Initialize the data as text in a variable*
*text1='''Comments*
*Sentiment*
*How does speech therapy help with a nonverbal to speak*
     *1*
*because all they do there is play with toys with him every time*
     *0*
*I'm confused guys help my son is 3years old now*
*0*
*he does is mumbles only no proper words*
*1*
*but he goes to speech therapy every month*
*1*
*Does it help*
*0*
*Step 3: Define the ChatGPT model inside method:*
*def generate_gpt3_response(user_text, print_output=False):*
    *completions = ai.Completion.create(model='text-davinci-003',   #davinci:ft-personal-2023-02-02-06-04-19',*
    *temperature=0.5,*
    *prompt=user_text,*
    *max_tokens=100,*
     *n=1,*
    *stop=[" Human:", " AI:"],*
 *)*

  *// Displaying the output can be helpful if things go wrong*
  *if print_output:*
    *print(completions)*
  *// Return the first choice's text*
  *return completions.choices[0].text*

*Step 4: Call the method to identify the sentiment of the sentence.*
*text2="My baby is not responding and his eye contact is very low."*
*text3=text1+" "+text4+" "+text2*
*#result=generate_gpt3_response()*
*result=generate_gpt3_response(text3)*
*print(result)*

### D. Proposed System Architecture

According to Fig. 7, a general architecture has been given where each model is associated with the BERT cosine similarity model. The working flow of BERT and ChatGPT has been given below.
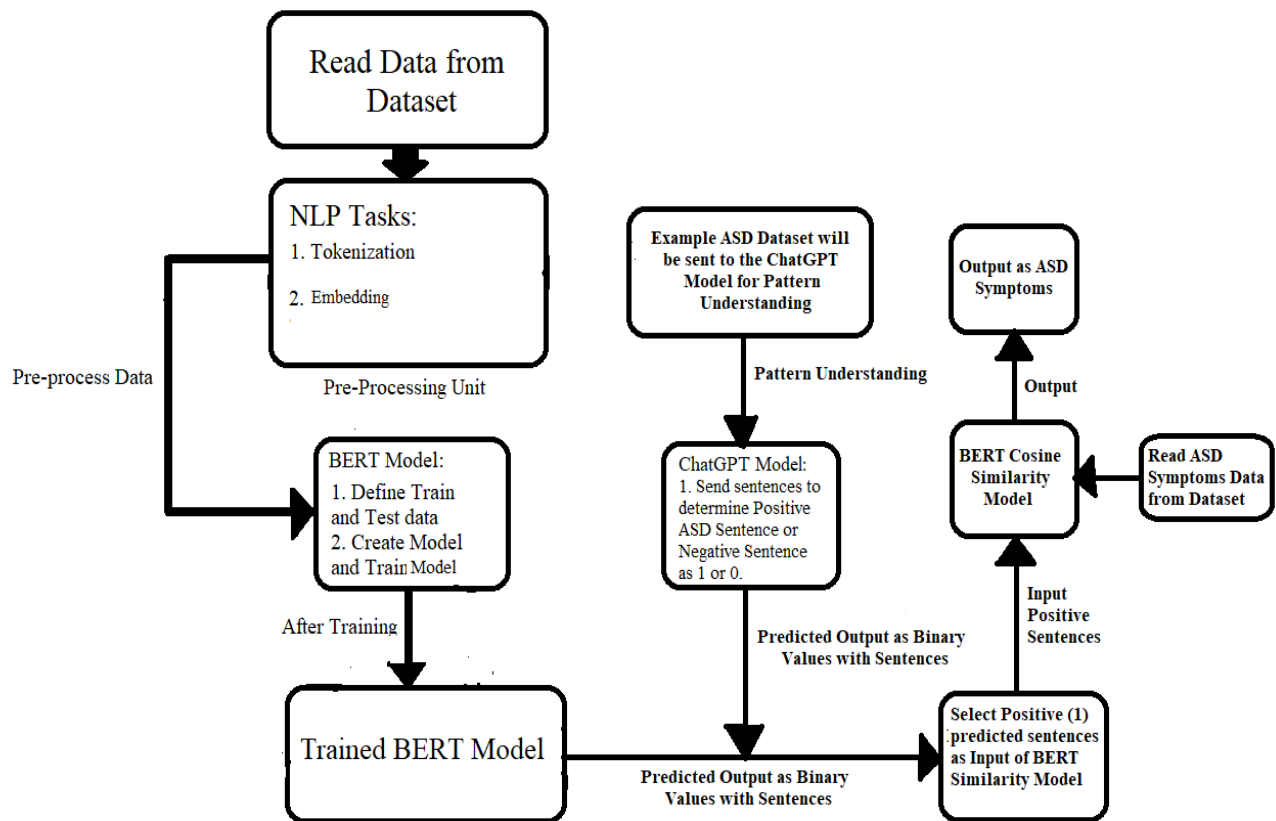
Fig. 7.  General flow of proposed system architecture.

Below is the algorithm summarizing the steps:

*1)* Select positive sentences from the input text.

*2)* Apply the BERT Cosine Similarity Model.

*3)* Calculate the cosine similarity between the input sentence and each positive sentence from the ASD symptoms dataset.

*4)* Select the sentence with the highest cosine similarity score.

*5)* Retrieve the label associated with the selected sentence from Table IV, indicating the corresponding ASD problem.

By utilizing the BERT Cosine Similarity Model and leveraging the labels from Table IV, the proposed system can effectively identify ASD problems based on the similarity between input sentences and the ASD symptoms dataset.

*The Algorithm in Python pseudo-code:*
*from sentence_transformers import SentenceTransformer, util*
*import pandas as pd*
*import pandasql as ps*

*// Intialize dataset in Dataframe*

*df = pd.read_csv(r"ASD_Symptoms.csv",encoding='Latin-1')*
*// List Array declare to store 'Comments', 'Sentiment value' and 'Cosine Score value*

*comments=[]*
*sentiment=[]*

*cosine_value=[]*
*// Function for bracket remove from Cosine value in Python*
*def listToStringWithoutBrackets(list1):*
    *return str(list1).replace('[','').replace(']','')*
*// BERT Cosine calculation function*
*def BERT_Cosine(strs):*
  *for ind in df.index:*
    *#print(df['Comments'][ind], df['Sentiment'][ind])*

    *sentences = [df['Comments'][ind], strs]*

    *model = SentenceTransformer('sentence-transformers/all-MiniLM-L6-v2')*

    *#Compute embedding for both lists*
    *embedding_1 = model.encode(sentences[0], convert_to_tensor=True)*
    *embedding_2 = model.encode(sentences[1], convert_to_tensor=True)*

    *comments.append(df['Comments'][ind])*
    *sentiment.append(df['Sentiment'][ind])*
    *score=util.pytorch_cos_sim(embedding_1, embedding_2)*

*cosine_value.append(listToStringWithoutBrackets(score.tolist()))*

  *dfc=pd.DataFrame(*
    *{'Comments': comments,*

```
 'Sentiment': sentiment,
 'Cosine_Scores': cosine_value
 })

// Dataframe to csv conversion with Cosine Score of each
sentence for extraction of Max Cosine value with
corresponding label value.
 dfc.to_csv('ASD_Cosine_Data.csv")
dfc['Cosine_Scores']=dfc['Cosine_Scores'].astype('float64')
 i = dfc['Cosine_Scores'].idxmax()
 return dfc['Sentiment'][i]


strs=pd.read_csv("ASD_New_Data.csv")
for st in strs['Comments']:
    result=BERT_Cosine(st)
    print(st,"=",result)
```

## IV. RESULTS AND DISCUSSION

### A. Result and Discussion of BERT Model

*1) Result*: The BERT model has been evaluated using some popular metrics like F1, Precision, Recall, Support, etc. The proposed research uses the BERT model as the binary classifier that will detect the sentences as positive or negative regarding ASD symptoms detection. The report of this binary classification has been given in Table III. But, before understanding the classification report, the confusion matrix of this proposed BERT model has been elaborated for a better clear view of this model.
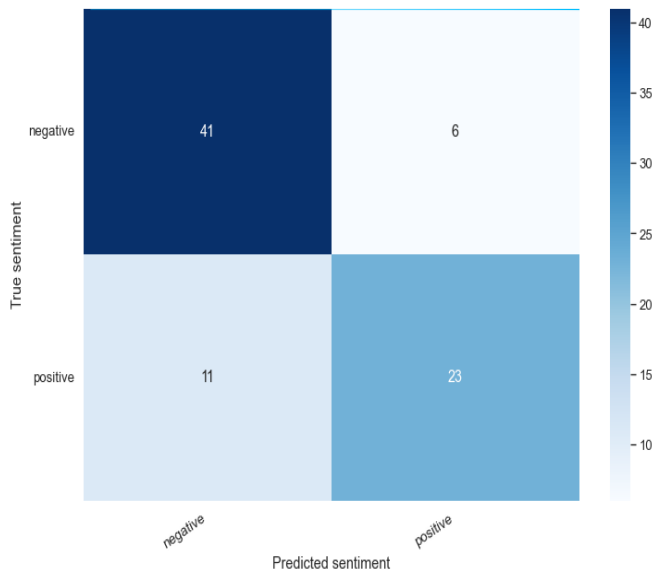


Fig. 8. Confusion matrix of proposed BERT model.

*2) Discussion*: According to Fig. 8. The proposed confusion matrix has two axes. The Y-axis is a true sentiment and X-axis is a predicted sentiment. True sentiment has both values positive and negative whereas predicted sentiment has the same positive and negative values. The number of sentences is 11 which are true positive sentiments but predicted as negative. In the next step, the number of true

positives is 29 and the model has predicted it as true. According to Fig. 7, true negative sentences are 41, and the proposed model has predicted these sentences as negatives whereas six true negative sentences have been predicted by this proposed model as positives. The number of correct predictions according to the true sentiment is greater than wrong predictions. The F1 score, Precision, Recall, and Support have been given in Fig. 8.

The F1 score is an important metric for the evaluation of machine-learning models. The F1 score will be calculated by the combination of Precision and the Recall value. The equation of the F1 score calculation has been given here.

$$F1 = (2 * (Precision * Recall)) / (Precision + Recall)$$

The Precision can be calculated using this formula where the number of True Positives (TP) is divided by the Total Number of True Positives (TP) and False Positives.

$$Precision = (TP / (TP+FP))$$

The Recall can be formulated by the number of True Positives (TP) divided by the total number of True Positives (TP) and False Negatives (FN).

$$Recall = (TP / (TP+FN))$$

The macro average computes the arithmetic mean according to the class. It is a straightforward average calculation method where the weighted average method refers to the proportion of each class support that is related to the sum of all support values. The count of correct occurrences of the class in the proposed dataset is called support. The imbalance support indicates the low scores of the report then the classification model can be remodified again.
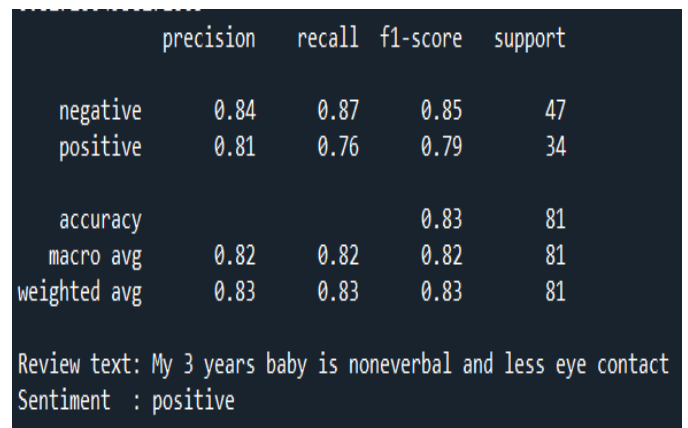


Fig. 9. Classification report of proposed BERT model.

Fig. 9 shows the classification report of the proposed BERT model where precision and recall values of negative and positive classes are 0.84, 0.87, 081, and 0.76 with support values 47 and 34. The F1 score of the negative and positive classes are 0.85 and 0.79. The accuracy of the proposed model is 0.83 (83%) according to the F1 score with 81 support values. The precision and recall values of macro and weighted averages are 0.82, 0.82, 0.83, and 0.83 where f1 scores are 0.82 and 0.83 with support values 81 and 81. An example

sentence has been sent to the proposed BERT model for sentiment prediction.

Review text: "My 3 years baby is nonverbal and less eye contact"

This sentence directly indicates the positive sentence of ASD symptoms because ASD children are nonverbal and have less eye contact. The predicted result can be seen in Fig. 9 as "Sentiment: positive".

### B. Result and Discussion of ChatGPT Model

*1) Result*: A pre-trained ChatGPT model has been used where the base model is 'text-davinci-003' which is a very powerful base language model in ChatGPT. Author Junjie Ye and et.al. described 'text-davinci-300' language model performance on various datasets. The classification report on 'text-davinci-300' language model has been elaborated in detail. The GPT series models like GPT-3, CodeX, InstructGPT, and ChatGPT have been considered to evaluate the performance on nine natural language understanding (NLU) tasks using 21 datasets as in [23]. The base models have been used to train their datasts. OpenAI has given the opportunity to train their base modeel on a particular dataset where each dataset has to be designed according to their dataset standard. However, the concern is that the base model is not fine-tuned as a ChatGPT pre-trained model. An API key is needed to use base ChatGPT base models and fine-tuned pre-trained base models. The fine-tuned pre-trained model has been considered in this research to utilize the advantages of fine-tuning and pre-trained. The main advantage is the accuracy of the prediction of the sentences regarding ASD symptoms.

The following code will show the initialization part of the fine-tuned pre-trained "text-davinci-003" base model of ChatGPT.

```
def generate_gpt3_response(user_text, print_output=False):
    completions = ai.Completion.create(model='text-davinci-003',    #davinci:ft-personal-2023-02-02-06-04-19',
    temperature=0.5,
    prompt=user_text,
    max_tokens=100,
        n=1,
    stop=[" Human:", " AI:"],
    )
```
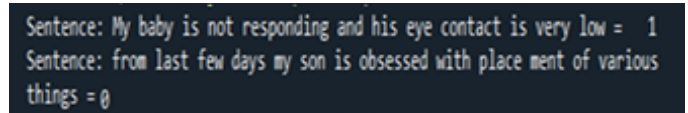
*2) Discussion*: The output from the proposed ChatGPT model according to the new parent's dialogues is good. An example sentence with sentiment value has to be sent to the ChatGPT model then it can understand the pattern and according to the pattern, it will start prediction according to the defined RLHF algorithm.

The output can be seen from the given Fig. 10 on sentences of parents' dialogues. The sentences are-

*a)* "*My* baby is not responding and his eye contact is very low."

*b)* "*from* last few days my son is obsessed with the placement of various things"

The first sentence is 1 means positive according to ASD symptoms whereas the second sentence is negative and ChatGPT returns 0.
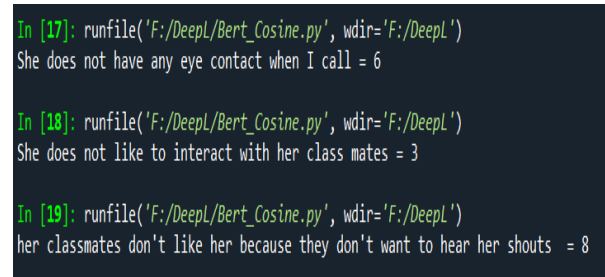


```
Sentence: My baby is not responding and his eye contact is very low = 1
Sentence: from last few days my son is obsessed with place ment of various things = 0
```

Fig. 10. Output of the proposed ChatGPT model.

### C. Result and Discussion of BERT Cosine Model

*1) Result*: The proposed cosine similarity model is responsible for identifying ASD symptoms from positive ASD sentences that have been predicted by the machine learning algorithms. The model's output is depicted in Fig. 11, where the sentence " She does not have any eye contact when I call" is labeled with 6.



```
In [17]: runfile('F:/DeepL/Bert_Cosine.py', wdir='F:/DeepL')
She does not have any eye contact when I call = 6

In [18]: runfile('F:/DeepL/Bert_Cosine.py', wdir='F:/DeepL')
She does not like to interact with her class mates = 3

In [19]: runfile('F:/DeepL/Bert_Cosine.py', wdir='F:/DeepL')
her classmates don't like her because they don't want to hear her shouts  = 8
```

Fig. 11. Example output result of BERT cosine similarity.

*2) Discussion*: Similarly, the sentences " She does not like to interact with her classmates" and " her classmates don't like her because they don't want to hear her shouts" are labeled with 3 and 8, respectively. Referring to Table IV, we can determine that label 6 corresponds to Eye Contact problems, label 3 indicates Behaviour problems, and label 8 represents hyperactive problems. These labels provide insight into the specific ASD problems associated with the detected symptoms. Upon identifying the ASD problems, appropriate therapies can be initiated based on the specific problem identified. Tailoring the interventions according to the detected problems is crucial in providing targeted support to individuals with ASD. These targeted therapies have the potential to significantly reduce the symptoms associated with ASD and improve overall well-being. The ability of the proposed system to accurately identify ASD problems through the analysis of positive sentences enables a more focused and tailored approach to therapeutic interventions. This personalized approach holds great promise in positively impacting individuals with ASD and enhancing their quality of life. By leveraging the system's ability to identify ASD problems accurately, individuals with ASD can receive more effective and personalized support, leading to improved outcomes and overall well-being.

## V.  LIMITATION

The proposed system leverages both transformer-based and LLM-based machine learning models to enhance its performance. Quantum machine learning models can be employed to improve accuracy by applying them to a large dataset. Additionally, collecting more data, especially accurate ASD-related parent dialogs, can significantly enhance the training and testing scores of the models. According to the language model, it has been observed that they are not very efficient in calculations like aggregation-type natural language response generation. As an example, ChatGPT is not able to do the right calculation of the sum of multiple float values at a time. This is the main limitation of language models. It is vital to ensure that all components of the system are functioning properly for the cosine similarity part to work effectively. Any issues or malfunctions in the system's components can impact the performance of the cosine similarity model, as it relies on accurate processing and selection of positive sentences.

## VI.  CONCLUSION

The proposed system is designed to process natural language text extracted from parents' dialogues to detect ASD symptoms. It utilizes sentiment analysis techniques to determine whether a sentence expresses positive or negative sentiments regarding ASD symptoms. To accomplish this task, the system employs BERT and ChatGPT models that have been trained on the provided dataset. After performing sentiment analysis, the system selects only the positive sentences for further analysis using the cosine similarity model. The system utilizes an ASD symptoms dataset, where each sentence is labeled with a value corresponding to a specific ASD symptom. By calculating the cosine similarity between the input sentence and each sentence in the ASD symptoms dataset, the system identifies the label value of the sentence with the highest similarity score. This label value indicates the specific ASD problem associated with the input sentence. One significant advantage of the proposed system is that it relies solely on text-based analysis. By leveraging text-based analysis and prioritizing affordability and accessibility, the proposed system has the potential to facilitate ASD detection and support in underserved regions, thus bridging the gap in ASD diagnosis and intervention.

## FUTURE WORK

To further enhance the output and accuracy of the proposed the provided dataset can be a valuable approach. This model can leverage the dataset to make predictions and improve the system's performance. By incorporating these models into the system and training them using the proposed dataset for ASD detection, the system can benefit from their advanced techniques and potentially achieve superior results. However, it is important to consider that transformer-based and LLM-based models like BERT and ChatGPT may not perform optimally when dealing with aggregation-type sentences. Therefore, it is crucial to carefully assess the sentences in the dataset and choose appropriate models accordingly. In summary, training the Quantum machine learning models using the proposed dataset for ASD detection represents a promising future development for the system.

## REFERENCES

[1]  C. Lord, M. Elsabbagh, G. Baird, J. Veenstra-Vanderweele, "Autism spectrum disorder", Lancet, vol. 392, pp. 508-520, 2018.

[2]  Azian Azamimi Abdullah, Saroja Rijal, Satya Ranjan Dash, "Evaluation on Machine Learning Algorithms for Classification of Autism Spectrum Disorder (ASD)", International Conference on Biomedical Engineering, pp.1-7, 2019.

[3]  Maitha Rashid Alteneiji, Layla Mohammed Alqaydi, Muhammad Usman Tariq, "Autism Spectrum Disorder Diagnosis using Optimal Machine Learning Methods", International Journal of Advanced Computer Science and Applications, vol. 11(9), pp.252-260, 2020.

[4]  D. Wall, J. Kosmicki, T. Deluca, E. Harstad, and V. Fusaro, "Use of machine learning to shorten observation-based screening and diagnosis of autism", Translational psychiatry, vol. 2(4), pp. e100, 2012.

[5]  Kruthi C H, Tejashwini H N , Poojitha G S, Shreelakshmi H S, Shobha Chandra K, "Detection of Autism Spectrum Disorder Using Machine Learning", International Journal of Scientific Research & Engineering Trends, vol. 7(4), pp. 2267-2271, 2020.

[6]  F. Tabtah,  "Autism Spectrum Disorder Screening: Machine Learning Adaptation and DSM-5 Fullfillment", 1st International Conference on Medical and Health Informatics, pp.1-6, 2017.

[7]  D. Aarthi, M. Udhayamoorthi, G. Lavanya, "Autism Spectrum Disorder Analysis Using Artificial Intelligence: A Survey", International Journal of Advanced Research in Engineering and Technology, vol. 11(10), pp. 235-240, 2020.

[8]  T. Amalraj Victoire, A. Ramalingam, A. Naresh, K.M. Nasimudeen, M. S. Jaya Kumar, "An Efficient Approach to Detect Autism in Child Using Machine Learning and Deep Learning", Journal of Theoretical and Applied Information Technology, vol. 99(20), pp. 4759-4769, 2021.

[9]  R. Gandhi, towardsdatascience. Retrieved june 7, 2018, fromtowardsdatascience.com:https://towardsdatascience.com/supportvector-machine-introduction-to-machine-learning-algorithms-934a444fca47, 2018.

[10]  F. Tabtah, "A mobile app for ASD screening", www.asdtests.com [accessed December 20th, 2017.

[11]  F. Tabtah, "Machine Learning in Autistic Spectrum Disorder Behavioral Research: A Review: To Appear in Informatics for Health and Social Care Journal. December, 2017.

[12]  American Psychiatric Association, (2013, 10 10). American Psychiatric Association, Retrieved from American Psychiatric Association: https://www.psychiatry.org/, 2013.

[13]  Abhijit Mohanta, Vinay Kumar Mittal, "Autism Speech Analysis Using Acoustic Features", 16th Intl. Conference on Natural Language Processing, pp. 85-94, 2019.

[14]  Sherif Kamel, Rehab Al-harbi, "Newly Proposed Technique for Autism Spectrum Disorder Based Machine Learning", International Journal of Computer Science & Information Technology (IJCSIT), vol 13(2), pp. 1-15, 2021.

[15]  Riccardo Fusaroli, Ethan Weed, Deborah Fein, Letitia Naigles, "Caregiver linguistic alignment to autistic and typically developing children: a natural language processing approach illuminates the interactive components of language development", Cognition, pp. 1-66, 2023.

[16]  Rafael A Calvo, David Nicholas Milne, M. Sazzad Hussain, Helen Christensen, "Natural language processing in mental health applications using non-clinical texts", Natural Language Engineering, vol. 23(5), pp.649-685, 2017.

[17]  Amrutha S M, K R Sumana, "Autism Spectrum Disorder Detection Using Machine Learning Techniques", International Research Journal of Engineering and Technology (IRJET), vol. 8(8), pp. 1252-1254, 2021.

[18]  Firsanova Victoria Igorevna, "The Description of the Autism Spectrum Disorder Question Answering Dataset", 27th International Conference on

Computational Linguistics and Intelligent Technologies Dialogue, pp. 1-8, 2021.

[19] Johnny Downs, Sumithra Velupillai et al., "Detection of Suicidality in Adolescents with Autism Spectrum Disorders: Developing a Natural Language Processing Approach for Use in Electronic Health Records", AMIA-2017, pp. 641-649, 2017.

[20] Parisa Moridian, Navid Ghassemi et al., "Automatic Autism Spectrum Disorder Detection Using Artificial Intelligence Methods with MRI Neuroimaging: A Review", Front Mol Neurosci, pp. 1-51, 2022.

[21] Zhenyu Mao, Yi Su et al., "Spatio-temporal deep learning method for ADHD fMRI classification", Information Sciences, pp. 1-11, 2019.

[22] Ashish Vaswani, Noam Shazeer, Niki Parmar, Jakob Uszkoreit, Llion Jones, Aidan N. Gomez, Lukasz Kaiser, Illia Polosukhin, "Attention Is All You Need", 31st Conference on Neural Information Processing Systems (NIPS 2017), pp. 1-15, 2017.

[23] Junjie Ye, Xuanting Chen, Nuo Xu et al., "A Comprehensive Capability Analysis of GPT-3 and GPT-3.5 Series Models", ArXiv, pp. 1-47, 2023

AUTHORS' PROFILE

Prasenjit Mukherjee has 14 years of experience in academics and industry. He completed his Ph.D. in Computer Science and Engineering in the area of Natural Language Processing from the National Institute of Technology (NIT), Durgapur, India under the Visvesvaraya PhD Scheme from 2015 to 2020. Presently, He is working as a Data Scientist at Vodafone Intelligent Solutions, Pune, Maharashtra, India, and doing his Post Doctoral (D.Sc.) in Computer Science from Manipur International University, Imphal, Manipur, India.

Gokul R S, a senior data scientist with over six years of experience in leading and executing data-driven projects for various domains. He is currently working as a deputy manager in Vodafone Intelligent Solutions, Pune in the area of Artificial Intelligence and Analytics. He received a B.Tech degree from Visvesvaraya Technological University, Karnataka. His research areas of interest include AI automation, machine learning, natural language processing, computer vision, and big data, prompt engineering, Quantum technologies, etc.
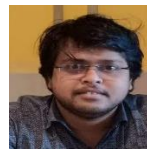
Sourav Sadhukhan has above 5 years of experience in Law and Management. He completed his Graduation in LLB from Calcutta University, Kolkata, India, and Post Graduate Diploma in Management from Pune Institute of Business Management, Pune, India. Presently he is a student of Executive Post Graduation in Data Science and Analytics from the Indian Institute of Management, Amritsar, India.

Dr. Manish Godse has 27 years of experience in academics and industry. He holds Ph.D. from Indian Institute of Technology, Bombay (IITB). He is currently working as an IT Consultant in the Bizamica Software, Pune in the area of Artificial Intelligence and Analytics. His research areas of interest include automation, machine learning, natural language processing and business analytics. He has multiple research papers indexed at IEEE, ELSEVIER, etc.

Dr. Baisakhi Chakraborty received the PhD. degree in 2011 from National Institute of Technology, Durgapur, India in Computer Science and Engineering. Her research interest includes knowledge systems, knowledge engineering and management, database systems, data mining, natural language processing, and software engineering. She has several research scholars under her guidance. She has more than 60 international publications. She has a decade of industrial and 22 years of academic experience.

# Optimizing Power Management in Distribution Networks: A Mathematical Modeling Approach for Coordinated Directional Over-Current Relay Control

Simardeep Kaur[1], Shimpy Ralhan[2], Mangal Singh[3], Mahesh Singh[4]

Department of EE, Shri Shankaracharya Technical Campus, Bhilai, Chhattisgarh, India[1, 2, 4]

Department of E&TC, Symbiosis Institute Technology, Symbiosis International (Deemed University), Pune, Maharashtra, India[3]

*Abstract*—Optimizing Power Management in Distribution Networks through Coordination of Directional Over-Current Relays summarizes a study or project focused on enhancing the management of power in distribution networks by optimizing the coordination of directional over-current relays. Directional over-current relays are critical components of power distribution systems, designed to safeguard the network against over-current faults while maintaining operational stability. Proper coordination of these relays is vital to ensure that faults are isolated and cleared efficiently without causing extensive disruptions. In this paper, a mathematical modeling approach is employed to address the optimization of power management in distribution networks. This approach likely encompasses the development of mathematical models and algorithms that consider factors such as fault types, fault locations, network topology, and relay settings to improve the coordination of directional over-current relays. Here, different optimization algorithms have been implemented to optimize the operating time of relays & hence power management. Cuckoo Search Algorithm (CSA), Fire-Fly Algorithm (FFA), Harmony Search Algorithm (HSA), and Jaya Algorithm are employed to solve the coordination problem for directional over-current relays (DOCRs) with different test systems. The outcomes of this research may have practical applications in power distribution systems, potentially leading to more resilient and responsive networks that better manage power distribution and reduce disruptions during faults and outages.

*Keywords—Optimization; Cuckoo Search Algorithm (CSA); Fire-Fly Algorithm (FFA); Harmony Search Algorithm (HSA); Jaya algorithm; directional over-current relays*

## I. INTRODUCTION

The duty of protective systems is to detect fault and remove it from the power network. In all the processes, the time of operation plays an important role. The accuracy and reducing the execution time of the protective relay is the challenging part of the optimization algorithm. The most important elements that are used in power system for protection are distance relays and overcurrent relays. For protection of power system elements, protection scheme with primary and back up protection are used. In any power system, primary protective relays must function at the instant of fault occurrence to remove the faulty section; at the condition, whenever the primary protective relay is unable to perform, then the backup protective relay is supposed to operate. It should operate after a certain period of time for protection of power system from

damage. The over-current protection relays are the frequently usable protection devices in the power system networks. For backup protection too, over-current relays are mostly used. But, the only protection scheme which provides the control to the power outages in some cases is the overcurrent protection. Unwanted relay tripping as a mal-operation for the backup protection relays has to be avoided. This is the major reason that over-current relay coordination in power system network is a major concern in protection system [1]. In the ring main distribution system for the management of power, the over-current relay coordination is a complex optimization problem with large number of constraints. The purpose is to find the minimum time of operation of primary relays as well as backup relays. It is to be noted that the mal-operation of relays is neglected during optimization. This results in making the problem more complex due to high number of constraints in modern day complex interconnected networks.

The optimum and accurate coordination of relays is necessary to recognize the fault efficiently within sort of time, to avoid possible outages and remove them from the power system network due to fault. The relay coordination problem is one of the most critical optimization problem because of large number of nonlinear constraints.

The motivation for this research stems from the growing importance of a robust, reliable, and efficient power distribution system. Modern society's increasing dependence on electricity, coupled with the advent of renewable energy sources, places new demands on distribution networks. The coordination of directional over-current relays becomes a vital consideration in ensuring that these networks can adapt to evolving conditions while continuing to provide a seamless power supply. Moreover, economic considerations drive utilities and power system operators to minimize downtime, reduce maintenance costs, and make efficient use of available resources. The potential benefits of an optimized relay coordination system are, therefore, multi-faceted, encompassing improvements in network resilience, safety, and cost-effectiveness.

Optimizing power management in distribution networks through the coordination of directional over-current relays offers a host of significant benefits. It enhances the overall reliability of power distribution, reducing service interruptions and downtime, which, in turn, leads to increased customer satisfaction and minimized economic losses. This optimization

also contributes to greater safety by swiftly isolating faults and preventing potential hazards. Furthermore, it enables utilities to operate more efficiently, saving on maintenance costs and utilizing network resources effectively. With a more resilient and responsive grid, integration of renewable energy sources becomes smoother, reducing environmental impact. In summary, the benefits encompass improved reliability, reduced downtime, enhanced safety, cost savings, efficient resource utilization, and environmentally responsible power management, ultimately fostering a more dependable and sustainable energy distribution infrastructure.

Power distribution networks play a pivotal role in ensuring a consistent and reliable supply of electricity, making the coordination of directional over-current relays a crucial aspect of network management. The literature on optimizing power management through relay coordination reveals a growing body of research aimed at enhancing the performance of distribution systems. S. S. Gokhale et al [2] have discussed about the relay coordination and the importance of the optimization of relay operating time. The phenomenon of Cuckoo search algorithm has been discussed and applied to optimize the operating time of relays. Single end fed network power system with six overcurrent protective relays is considered as a test system for relay coordination problem. Chabanloo et al [3] have discussed the modified objective function and various characteristics of overcurrent relay and distance protection has been studied. The application of genetic algorithm, in order to solve optimization problem has been discussed. Mousavi et al [4] have discussed about the objective function minimization with constraints in this article. Constraints always affect the results and the operation time of the algorithm. The handling of constraints would be different for different optimization algorithms. Jagdish Madhukar Ghogare et al [5] have discussed radial and loop system coordinates with genetic algorithm. The different operators of genetic algorithm along with case study of symmetrical and unsymmetrical information set has been implemented. The relay coordination problem identification with their constraints has been studied and calculated for ten relay test system. Divya S Nair et al [6] have briefly discussed about the protective system and use of appropriate protective relays to protect the power system elements. The calculation of constraints and objective function parameters has been discussed with the help of fourteen relay system. The system is further optimized with genetic algorithm. The effect of relay operation time with different fault condition has shown in this paper. Abdul Wadood et al [7] have used the root tree algorithm (RTO), inspired by the random movement of roots, to search for the global optimum, in order to best solve the problem of overcurrent relays (OCRs). C.A. Castillo et al [8] have proposed the invasive weed optimization for the relays with non-standardized inverse time curves for improving overcurrent relay coordination performance. The model and implementation of optimization algorithm for coordination must be capable of handling increased problem dimension and constraints. Zahra MORAVEJ et al [9] have implemented the grey wolf optimizer algorithm and it has been used as an optimization tool to find optimum settings. Ahmed Korashy et al [10] have proposed a modified version for Water Cycle

Algorithm (WCA), referred to as MWCA to effectively solve the optimal coordination problem of DOCRs. In the proposed technique, the search space has been reduced by increasing the C-value of traditional WCA, which effects on the balance between explorative and exploitative phases, gradually during the iterative process in order to find the global minimum.

The metaheuristic techniques are used on a daily basis for industrial planning, resource allocation, econometrics problems, scheduling, decision making engineering, and computer science applications. In this work, we have dealt with the comparative study of the different optimization techniques; namely, Cuckoo Search Algorithm, Firefly Algorithm, Harmony search algorithm and Jaya algorithm. These methodologies are applied for the coordination of directional overcurrent protective relays. The results obtained are validated when they accomplish all the constraints. The equality and inequality constraints show the coordination boundary for each and every primary and backup relay pair; which are having fault very near to the primary protective relays. The number of constraints will lead to an increase in the processing time of optimization process of any algorithm. For the small systems, it will take less time to get the optimum result, but in case of large systems, the number of constraints will increase leading to a large time for processing. If we reduce the constraints by neglecting them, the problem under consideration will not offer the appropriate results. For best results, the optimized value should follow the constraints religiously. Optimizing power management through the coordination of directional over-current relays brings about numerous implications, from immediate improvements in grid reliability and safety to longer-term economic benefits and environmental sustainability. These implications not only enhance the performance of power distribution networks but also contribute to the broader goals of energy sector efficiency, safety, and environmental responsibility.

Our paper is structured as follows: Section II highlights the basic function of relays and relay coordination in radial and ring main feeder system. Section III elaborates about the objective function and their constraints. Jaya algorithm is presented in Section IV, whereas, the different case studies have been discussed for different optimization algorithm and are presented in Section V along with the comparison of optimum results and their discussion with proposed Jaya algorithm. At last, Section VI provides the conclusion and remarks.

## II. DIRECTIONAL OVERCURRENT RELAY IN DISTRIBUTION NETWORK

Directional Overcurrent Relays are devices which provide the protection against the interruption of the healthy supply system from the unhealthy fault situations. In the electrical power system, the coordination is the major factor because the devices are interconnected. Therefore, when fault occurs at certain point, it will definitely affect the entire system and can lead to major damage in the system. The solution of such a problem is solved by the coordination of relays. The least operating time can be achieved by using the optimization tools.

## A. Coordination of Relays

Relay coordination is essential part of any protection system. When any network is protected with the distance relays, main and backup relay pairs are provided for each line. By arranging the overcurrent relays and distance relays, protection of lines gets expanded for better protection. If any disturbance occurs, at first, the primary distance (main) relay actuates. After that the overcurrent relay will be actuated. If this is unable to clear the fault, at a prior time and fails to actuate for any reason, distance relays will operate [11]. And, if it is also fails to operate, the backup protective overcurrent relay must immediately detach the faulty section from the network. As elaborated in Fig. 1 and Fig. 2, two constraints have to be added for coordination problems, as in (1) and (2) to create the sequential protection.

$$t_b\left(F_3\right) - t_{z2} \geq CI' \tag{1}$$

$$t_{z2} - t_m\left(F_4\right) \geq CI' \tag{2}$$
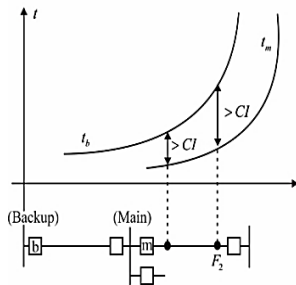


Fig. 1.   Coordination of overcurrent relays.
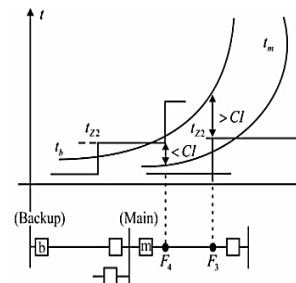


Fig. 2.   Distance and overcurrent relay coordination.

Where, $t_m$ is overcurrent relay operating time and the operating time of second zone protective relay is$t_{z2}$. At this condition when there is a new time interval for coordination (CI'); it should be defined between distance relays and overcurrent relays (not be the similar value as CI). This is used to establish the coordination of protective relay pairs

## B. Over-current Relays Coordination in Radial Feeder System

Whenever the fault occurs, it is detected by both primary protective relays and backup protective relays. The operating time of relays, i.e., primary and back up is different, since the primary protective relay operating time is less than the backup protective relays, the primary protective relay will operate first. There is a radial distribution feeder system with two relays as depicted in Fig. 3. When fault occurs at point labeled as F, the

relay $R_B$ will operate first. Assuming the relay tripping time of relay $R_B$ is set to 0.2 seconds, the relay $R_A$ should operate after 0.2 sec plus CI. If the backup protective relay activates before the time of working of primary relay, it is called mal-operation [3].



Fig. 3.   Simple radial feeder network.

## C. Coordination of Over-Current Protective Relay in Ring Main Feeder Distribution System

It is essential to maintain the selectivity and sensitivity of protective devices at point A and B. The test system is presented in Fig. 4, which allows to maintain the supply to all connected loads at the condition of fault on any of the part of network and keeps the supply continuous [12]. Here, relay 1, and relay 8 are non-directional relays, apart from those, remaining relays are directional over-current relays (relay 2, 3, 4, 5, 6, and 7). All the directional relays are having their direction of tripping, which are away from the connected bus, shown in Fig. 4.
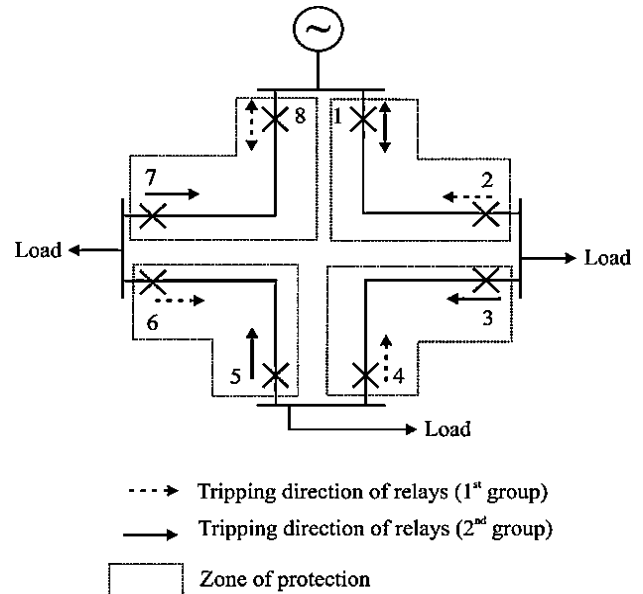


Fig. 4.   A simple ring main feeder network (relay1 & 8 are non-directional and remaining relays are directional).

For the purpose of relay coordination, relay number 2, 4, 6, and 8 will make a group. Similarly, relay numbers 1, 3, 5, and 7 will form another group. Relay coordination has to be established from the relay 2, for group one.

The relay operating times has to take as $T_{R8} > T_{R6} > T_{R4} > T_{R2}$ for group one. Similarly, for group two, the relay setting initiates from relay 7. Operating time of relay has to take as $T_{R1} > T_{R3} > T_{R5} > T_{R7}$ for group two. The real operation time of relays has a constrained problem. The operating time should follow all the constraints for better

selectivity and sensitivity of relay coordination. Since the size and complexity of the power system network goes on increasing, the number of constraints will increase and it becomes more complex problem to coordinate the relays.

### III. RELAY COORDINATION OPTIMIZATION PROBLEM

The ideal characteristics for IDMT relay shows that the operating time is inversely proportional to the fault current. Hence, overcurrent relay will operate fast after sensing a very large amount of current. However, IDMT relays are categorized into three types: standard inverse, extremely inverse and very inverse types. Relay characteristics depends on the type of standards selected for its operation. This can be defined by user or set by the ANSI, IEEE, IEC standards. Overcurrent relays are generally used for protection against inter phase faults and line to ground faults [13]. The operating time of the relay tracks the time over current curve, where the time delay be influenced by the value of current. There are two decisive factors, TDS and Plug Setting. The tripping time of the relay is closely related to TDS, plug setting and the fault current ($I_f$). The total operating time is given by a non-linear mathematical expression in (3) with respect to the constraint.

$$T = \frac{\alpha \times TDS}{\left(\dfrac{I_f}{PS \times CT_{pr}}\right)^{\beta}} - \gamma \tag{3}$$

$\alpha, \beta$ and $\gamma$ are constants. According to IEEE standards [14], the values of these constants are given by 0.14, 0.02 and 1.0, respectively. $I_f$ is the fault current at the primary terminal of current transformer (CT), where the fault occurs. $CT_{pr}$ represents the primary of CT. The ratio between $I_f$ and $CT_{pr}$ provides the current sensed by the protective relay denoted by $I_{relay}$ shown in (4).

$$I_{relay} = \frac{I_f}{CT_{pr}} \tag{4}$$

#### A. Relay Coordination Objective Function

The objective function is stated as the sum of operating times of all the primary relays expressed in terms of the product of Time dial setting (TDS) for each relay which is to be minimized, and a constant which is a function of ratio of fault current and pick up values of current. The inequality constraints framed according to close in fault and far end fault have the proper coordination margin for each primary/backup relay pair for a fault very close to relay pair.

To obtain the parameters of TMS and set $I_{set_i}$, the objective function and constraints of the problem is defined in (5) and (6) is given by

$$\text{Minimize}: \sum_{i=1}^{n} t_{op} \tag{5}$$

$$t_{op} = \left(TSM_i, I_{set_i}\right) = \frac{3TMS_i}{\log\left(\dfrac{I_{sc_i}}{I_{set_i}}\right)} \tag{6}$$

where n is the total number of protective relays,

$t_{op}$ is the operating time of $i_{th}$ relays,

*TSM* is the Time Setting Multiplier,

$I_{sc_i}$ is the short circuit current,

$I_{set_i}$ is the pre-fault current.

As in Fig. 5, a near end fault is a fault that occurs close to the relay and a far end fault is a fault that occurs at the other end of the line [15]. In directional over-current relays, the magnitude of the fault currents detected at different locations will be different. In Fig. 5, a radial feeder is shown which the simplest distribution system employing directional overcurrent relays R_primary and R_backup. Here, R_primary is the primary relay for the near end fault and R_backup is the backup relay for the same fault. The operating time of primary relay is T_primary for near-end fault and operating time of backup relay is T_backup which is greater than T_primary. Thus, the operating time of the backup protection should be equal to the operating time of primary protection plus the operating time of the primary circuit breaker.
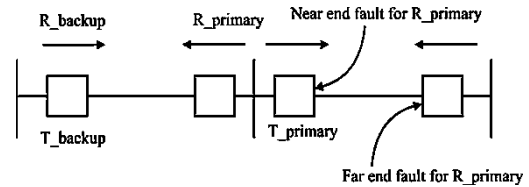


Fig. 5. Near end and far end faults for primary relay.

In coordination studies, the sum of the tripping times of all the primary protective relays to clear a near or far end fault can be considered as an objective function that is to be reduced. Therefore, the objective function to minimize (Z) can be expressed as given in (7).

$$\text{Minimize } Z = \Sigma_{i=1}^{N} T_{pri}^{i} + \Sigma_{j=1}^{M} T_{pri}^{j} \tag{7}$$

$$\text{where, } T_{pri}^{i} = \frac{0.14 \times TDS^{i}}{\left(\dfrac{I_F^{i}}{\left(PS^{i}\right) \times CT_{pr}^{i}}\right)^{0.02} - 1} \tag{8}$$

$$T_{pri}^{j} = \frac{0.14 \times TDS^{j}}{\left(\dfrac{I_F^{j}}{\left(PS^{j}\right) \times CT_{pr}^{j}}\right)^{0.02} - 1} \tag{9}$$

$$i = 1, 2, 3 \dots N; j = 1, 2, 3 \dots n$$

where $T_{pri}$ is operating time of the primary relay; $CT_{pr}$ is the primary of CT and *TDS* is for Time Dial Setting for relay.

The essential constraints for optimization of relay coordination problem are given as in (10) and (11).

$$TSM_{\min i} \leq TSM_i \leq TSM_{\max i} \tag{10}$$

$$I^{Max}_{load_i} < I_{set_i} < I^{Min}_{fault_i} \tag{11}$$

The selection of TSM is used for each pair of main and backup relay (*m, b*). It is also used for errors regarding to zone of protection $z_m$. The failures are identified at the fault points. The operating time constraints give the range of operation of relays. The maximum and minimum value of fault current defines the pickup value of an overcurrent relay [16].

### B. Constraints of Relay Coordination

Three constraints are considered for the minimization problem. The first constraint is TDS of the relay, which is the delay in time. Earlier the relay get operates each and every time the fault current becomes equal to or above the Plug Settings of relay (12).

$$TDS^i_{\min} \leq TDS^i \leq TDS^i_{\max} \tag{12}$$

*i* varies between 1 and $N_i$. $TDS^i_{\min}$ and $TDS^i_{\max}$ are the limits between minimum and maximum value of TDS allowed, which are 0.05 and 1.10 sec, respectively. The second constraint concerning PS takes the form (13).

$$PS^i_{\min} \leq PS^i \leq PS^i_{\max} \tag{13}$$

where *i* varies between 1 and $N_j$. $PS^i_{\min}$ and $PS^i_{\max}$ are the minimum limits and maximum limits of PS which are 1.25 and 1.50, respectively. Relay coordination functioning time is related to the fault current which can be seen by the protective relays and the pickup current setting. Relay functioning time is also depends on the category of the relay and it can be determined by standard characteristic curves of the relay or mathematical formula [2]. Hence, the relay operating time is defined by (14).

$$T^i_{\min} \leq T^i \leq T^i_{\max} \tag{14}$$

$T^i_{\min}$ is the minimum value and $T^i_{\max}$ is the maximum values for the relay operating time, which are 0.05 and 1.00, respectively. The organization time interval between the primary protective relays and the backup protective relays essentially verified during the optimization procedure. The coordination constraint between the primary and backup protective relays for relay coordination is given as (15).

$$T_{backup} - T_{primary} \geq CTI \tag{15}$$

where $T_{primary}$ is the functioning time of primary protective relays and $T_{backup}$ is functioning time of backup protective relays. The minimum coordination time interval is shown by $CTI$. For electromechanical type of relays, $CTI$ varies between 0.30 sec and 0.40 sec. Similarly, for numerical relays, the value lie $CTI$ varies between 0.10 sec and 0.20 sec. The

value of $T_{backup}$ and $T_{primary}$ can be determined by (16) and (17), respectively.

$$T^i_{backup} = \frac{0.14 \times TDS^x}{\left(\frac{I^i_F}{\left(PS^x\right) \times CT^i_{pr}}\right)^{0.02} - 1} \tag{16}$$

$$T^i_{primary} = \frac{0.14 \times TDS^y}{\left(\frac{I^i_F}{\left(PS^y\right) \times CT^i_{pr}}\right)^{0.02} - 1} \tag{17}$$

where $T^i_{backup}$ is actuating time of the backup relay; $T^i_{primary}$ is actuating time of the primary relay; is the primary of CT and $TDS$ is for Time Dial Setting for relay.

## IV. JAYA ALGORITHM

The Jaya algorithm, proposed by Venkata Rao [17], is a global search-based population method. This algorithm is based on the concept that it always tries to reach the best solution and to avoid failure solutions. Moreover, it is easy to implement as it requires only common controlling parameters (population size and number of generations). The algorithms which fall under the category of evolutionary and swarm intelligence require proper tuning of specific parameters which are related to algorithm in addition to tuning of common controlling parameters. A change in the tuning of the algorithm specific parameters influences the effectiveness of the algorithm. The Jaya algorithm does not require any algorithm specific parameters and it only requires the tuning of the common controlling parameters for its working.

Step I: Declare all the design variables of the objective function. In the search space, generate the population size (N) which is random. Each variable in the population generated is a vector and there are n number of design variables and is given by (18)

$$x_{j=}x_{j,i}(l) + rand[0,1] \times \left(x_{j,i}(u) - x_{j,i}(l)\right) \tag{18}$$

$$i = 1,2,3\ldots.N; j = 1,2,3\ldots.n$$

Where $x_{j,i}(l)$ represents the minimum value and $x_{j,i}(u)$ represents the maximum value,

$rand[0,1]$ represents the generation of random numbers between 0 and 1, $N$ represents the population size.

Step II: Set the number of iterations in the counter and let the iteration counter be F. Call the fitness function and update the population size while it reaches the number of iterations. Consider the $G^{th}$ iteration and the absolute value of the candidate solution as $\left|x_{j,i,G}\right|$.

Step III: During the $G^{th}$ iteration, let the variable generated be $x_{j,i,G}$ which is used to generate a vector $x^v_{j,i,G}$ corresponding to it. This value obtained should lie within the

minimum and maximum bounds framed and can be given as (19)

$$x^v_{j,i,G} = \begin{cases} 2x^l_j - x^v_{j,i,G} & \text{if } x^v_{j,i,G} < x^l_j \\ 2x^u_j - x^v_{j,i,G} & \text{if } x^v_{j,i,G} > x^u_j \\ x^v_{j,i,G} & \text{else} \end{cases} \qquad (19)$$

Step IV: The expression for the vector at the $G^{th}$ iteration is given by (20)

$$x^v_{j,i,G} = x_{j,i,G} + r_{1,j,G}\left(x_{j,best,G} - \left|x_{j,i,G}\right|\right) - r_{2,j,G}\left(x_{j,worst,G} - x_{j,i,G}\right) \qquad (20)$$

where $x_{j,best,G}$ and $x_{j,worst,G}$ represent the values of the variable j for the best and the worst candidate, respectively, $r_{1,j,G}$ and $r_{2,j,G}$ are the random numbers in the range [0,1],

$$r_{1,j,G}\left(x_{j,best,G} - \left|x_{j,i,G}\right|\right)$$

represents the term working towards achieving the best solution,

$$r_{2,j,G}\left(x_{j,worst,G} - x_{j,i,G}\right)$$

represents the term working towards avoiding the worst solution.

Step V: At the end, depending on the objective function, vector $x^v_{j,i,G}$ is compared to its corresponding variable $x_{j,i,G}$ and if it has lower value, it survives to the consecutive generation or else it will be retained in the population. Fig. 6 shows the flow chart of Jaya algorithm [4].

The flowchart of Jaya algorithm is demonstrated in Fig. 6.
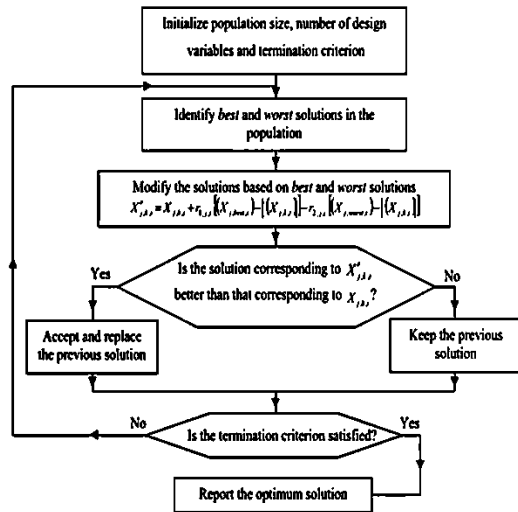


Fig. 6. Flow chart for Jaya algorithm.

The parameters of different optimization techniques used in this paper is listed in the Table I the number of iterations are kept equal for all the optimization techniques used [19, 20]. The algorithm parameters in the proposed method for optimizing power management through the coordination of directional over-current relays have a profound impact on the algorithm's performance and the outcomes of the optimization process. The choice of these parameters can significantly affect how quickly the algorithm converges to a solution and the quality of that solution. For instance, parameters related to learning rates, mutation rates, or step sizes can either expedite convergence or lead to overshooting the optimal solution if set too high, or slow down the process if set too low. The careful selection and tuning of algorithm parameters are pivotal to achieving effective and efficient power management optimization, ensuring robustness, scalability, and the ability to adapt to varying network conditions.

TABLE I. PARAMETERS OF OPTIMIZATION TECHNIQUES

| CS Parameters | FF Parameters | HS Parameters | Jaya Parameters |
|---|---|---|---|
| Discovery Rate of alien eggs = 0.25 No. of nests:10 Iteration=10 | No. of fireflies:100 Alpha = 0.5 Beta min=0.2 Gamma=1 Iteration=10 | Harmony memory size=10 Harmony consideration rate=0.9 Minimum Pitch Adjusting Rate=0.4 Maximum Pitch Adjusting Rate=0.9 | Population size=10 Run=10 Maximum fitness=100 |
| Maximum Iteration:100 | Maximum Iteration:100 | Maximum Iteration:100 | Maximum Iteration:100 |

## V. ANALYSIS OF JAYA ALGORITHM

### A. Analysis of 6-Bus, 10-Relays System

Single-line diagram of 220KV power system of Serum Institute, Pune India is shown Fig. 7 [18]. This is fed to Serum Substation 6 bus radial system. It has 10 relays, which is shown in Fig. 8. The short-circuit data are taken from the test data set. The CT ratio of 100/1 A is used for relay 1, 1000/1 A for relay 2, 300/1 A for relay 3 and 7, 500/1 A for relay 4 and 8, 600/1 A for relays 5, 6, 9, 10. The transformer rating for transformer $T_1$ has 400/220 KV, 315 MVA and %Z is 12.25%. Similarly for transformer $T_2$, 400/220 KV, 501 MVA, %Z is 12.25%, and for transformer $T_3$, 220/22 KV 30 MVA, %Z is 14.07%. Transmission line has double circuit line having lengths $L_1 = 13.6$ km, $L_2 = 12.40$ km; $L_3 = 45$ km; $L_4 = 36$ km; and line$L_5, L_6, L_7, L_8$ has length of 4 km. There are conductor spacing for vertical and horizontal line are 5.5 and 11 meters, respectively.
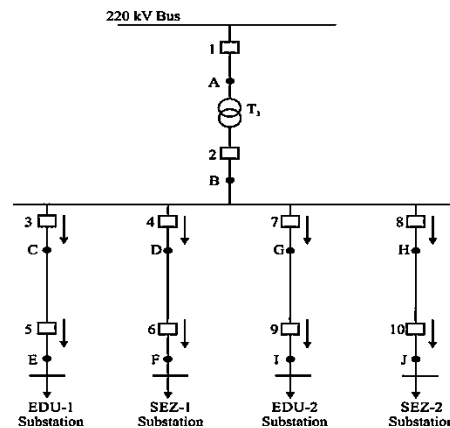


Fig. 7. Single line diagram of 6 bus, 10 relays test system.

The base MVA for calculating sequence currents is taken 500 MVA to construct sequence networks (positive, negative and zero). The load flow calculations are done with a conventional load flow analysis at all fault points based on those sequence networks. Primary and backup protective relay pairs are calculated and located in the system based on fault locations.

Table II demonstrates comparative analysis of some of the different nature inspired algorithms and the proposed Jaya algorithm. After the process of optimization, results in terms of relay operating time and total operating time for protective system given by some different algorithms. Minimum and maximum operating time limit has been set to 0.5 sec and 1 sec, respectively. Nineteen inequality constraint equations are formulated. The number of iterations would be same for all algorithms and is taken 100 iterations.

TABLE II. ANALYSIS OF 6 BUS, 10 RELAYS TEST SYSTEM FOR DIFFERENT OPTIMIZATION ALGORITHMS

| Relay number | Relay operating time (sec) | | | |
|---|---|---|---|---|
| | Cuckoo search algorithm | Fire-fly Algorithm | Harmony Search Algorithm | Jaya Algorithm |
| 1 | 0.2805 | 0.4106 | 0.0321 | 0.4160 |
| 2 | 0.1073 | 0.2875 | 0.0235 | 0.1791 |
| 3 | 0.3513 | 0.1846 | 0.0041 | 0.3949 |
| 4 | 0.3295 | 0.1941 | 0.0276 | 0.4514 |
| 5 | 0.2197 | 0.0488 | 0.0533 | 0.1997 |
| 6 | 0.3573 | 0.0417 | 0.0053 | 0.4840 |
| 7 | 0.0335 | 0.2060 | 0.0259 | 0.1893 |
| 8 | 0.4969 | 0.1695 | 0.1829 | 0.0986 |
| 9 | 0.0702 | 0.0488 | 0.1429 | 0.3402 |
| 10 | 0.2329 | 0.0417 | 0.1094 | 0.4547 |
| $Z_{min}$ | 3.3945 | 3.3148 | 1.5206 | 1.3383 |

Fig. 8 shows the comparative analysis chart of the 6 bus, 10 relays test system along their objective function results and respective optimization techniques.
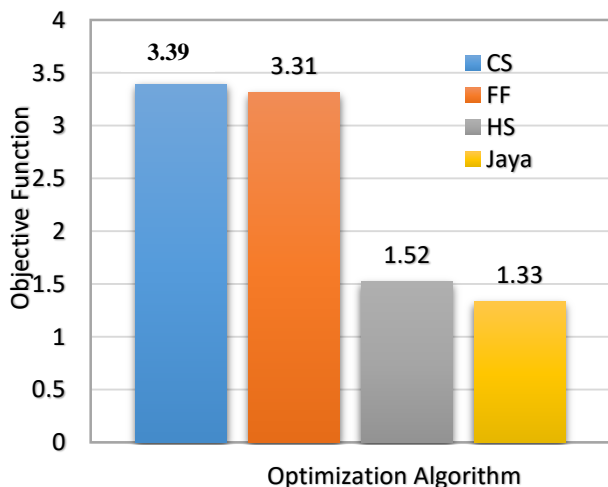


Fig. 8. Objective function values from various optimization techniques for 6 bus test system.

The results obtained from different optimization algorithms along the proposed Jaya algorithm using conventional relay characteristic are shown in Table II. The aim of the relay coordination optimization problem is to reduce the total time of operating for relays. Table shows the operating time of each relays, which can be comparable with the result from different algorithms. The overall total relay operating time has to be minimized. Proposed Jaya algorithm gives the best result among other algorithms. The evaluation time for each algorithm are different as per their parameters and number of populations. The number of population will increase the possibility to reach the most optimum solution, but it would also take more time to evaluation.

TABLE III. STATISTICALLY ANALYSIS OF 6 BUS, 10 RELAYS TEST SYSTEM

| Parameter | CSA | FFA | HSA | JA |
|---|---|---|---|---|
| Mean | 0.2479 | 0.1633 | 0.06070 | 0.3208 |
| Standard Deviation | 0.1456 | 0.1228 | 0.06227 | 0.1406 |
| 95% CI for the mean | 0.1438 to 0.3520 | 0.07551 to 0.2512 | 0.01616 to 0.1052 | 0.2202 to 0.4214 |
| Standard error of the mean | 0.04603 | 0.03882 | 0.01969 | 0.01447 |

The statistical evaluation of the results obtained by different optimization techniques namely Cuckoo Search Algorithm (CSA), Fire-Fly Algorithm (FFA), Harmony Search Algorithm (HSA), and Jaya algorithm are presented in Table III. It shows the standard deviation and the standard error of the mean are 0.04603, 0.03882, 0.01969 and 0.01447 obtained by CSA, FFA, HSA and Jaya algorithm. From this table, it can be observed that the best value of standard deviation error is minimum (0.01447 sec) is obtained by Jaya which is the least value compared to the other techniques. This means that the Jaya algorithm gives the lowest standard deviation (0.01447 sec).

*B. Analysis of for 8-Bus, 14-Relays System*

The single line diagram for 8-bus test system is shown in Fig. 9 [1]. Which are contains 14 relays. There is also a link to additional network at various bus, as shown in Fig. 3, which are modeled by taking a base of 400 MVA for calculating the short circuit current. The short-circuit data for different fault conditions are obtained. The primary and back-up relay pairs are took from manual calculated short-circuit analysis and short circuit currents are calculated as per conventional load flow analysis. The CT ratio for relays 3, 7 9, 14 is considered as 800/5 A, for rest of relays CT ratio is considered is 1200/5 A. The population size is taken for a different algorithm is 10, and the number of iterations would be same for each algorithm, which has taken 100.

Comparative analysis of the various algorithms with the proposed Jaya algorithm is shown in Table IV. Finally the results in terms of relay operating time and TDS for main relays. Minimum and maximum operating time limit has been set to 0.5 sec and 1 sec, respectively. Twenty inequality constraint equations are formulated. The number of iterations would be same for all algorithms and is taken 100 iterations.
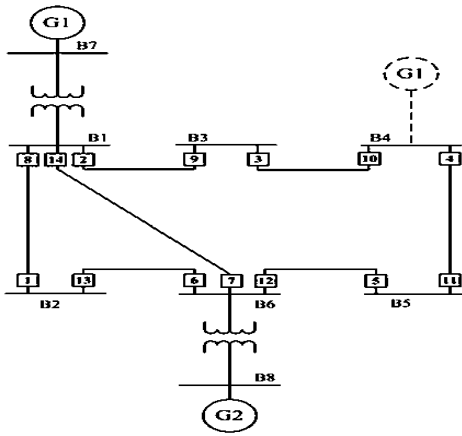
Fig. 9. Single line diagram of 8 bus, 14 relays test system.



Fig. 10. Objective function values from various optimization techniques for 8 bus test system.

TABLE IV. ANALYSIS OF 8 BUS, 14 RELAYS TEST SYSTEM FOR DIFFERENT OPTIMIZATION ALGORITHMS

| Relay number | Relay operating time (sec) | | | |
|---|---|---|---|---|
| | Cuckoo search algorithm | Fire-fly Algorithm | Harmony Search Algorithm | Jaya Algorithm |
| 1 | 0.2805 | 0.4106 | 0.2186 | 0.0026 |
| 2 | 0.1073 | 0.2875 | 0.1111 | 0.0844 |
| 3 | 0.3513 | 0.1846 | 0.0600 | 0.0057 |
| 4 | 0.3295 | 0.1941 | 0.0319 | 0.0041 |
| 5 | 0.2197 | 0.0488 | 0.0901 | 0.1290 |
| 6 | 0.3573 | 0.0417 | 0.2315 | 0.2512 |
| 7 | 0.0335 | 0.2060 | 0.0024 | 0.0094 |
| 8 | 0.4969 | 0.1695 | 0.0390 | 0.0163 |
| 9 | 0.0702 | 0.0488 | 0.0874 | 0.0768 |
| 10 | 0.2329 | 0.0417 | 0.1343 | 0.0155 |
| 11 | 0.3212 | 0.3721 | 0.1173 | 0.2630 |
| 12 | 0.3432 | 0.3682 | 0.0014 | 0.1384 |
| 13 | 0.2981 | 0.2234 | 0.0450 | 0.0970 |
| 14 | 0.3357 | 0.3296 | 0.1846 | 0.0642 |
| $Z_{min}$ | 3.4233 | 3.3045 | 1.3553 | 1.1581 |

Fig. 10 shows the comparative analysis chart of the 8 bus, 14 relays test system along their objective function results and respective optimization techniques.

The results obtained from different optimization algorithms along the proposed Jaya algorithm using conventional relay characteristic are shown in Table IV.

The standard deviation and the standard error of the mean as shown in Table V are 0.03386, 0.03502, 0.01995 and 0.01339 obtained by CSA, FFA, HSA and Jaya algorithm. From this table, it can be observed that the best value of standard deviation error is minimum (0.01339 sec) is obtained by Jaya which is the least value compared to the other techniques. This means that the Jaya algorithm gives the lowest standard deviation (0.01339 sec).

TABLE V. STATISTICALLY ANALYSIS OF 8 BUS, 14 RELAYS TEST SYSTEM

| Parameter | CSA | FFA | HSA | JA |
|---|---|---|---|---|
| Mean | 0.2698 | 0.2090 | 0.09676 | 0.08269 |
| Standard Deviation | 0.1267 | 0.1310 | 0.07466 | 0.08751 |
| 95% CI for the mean | 0.1967 to 0.3430 | 0.1334 to 0.2847 | 0.05365 to 0.1399 | 0.03216 to 0.1332 |
| Standard error of the mean | 0.03386 | 0.03502 | 0.01995 | 0.01339 |

*C. Analysis of 14-Bus, 40-Relays System*

The single line diagram of IEEE 14-bus test network is shown in Fig. 11 [21], which contains 40 relays. The short-circuit data are taken from the test data set. In this network, the system has 5 generators, 20 transmission lines and it is fed through two transformers $T_1$ and $T_2$. The power base of the system is 138 kV, 100 MVA. The range of TDS is set to be in between 0.5 sec to 1 sec for all the algorithms. The CT ratio is considered as 500/1 A for all the relays.
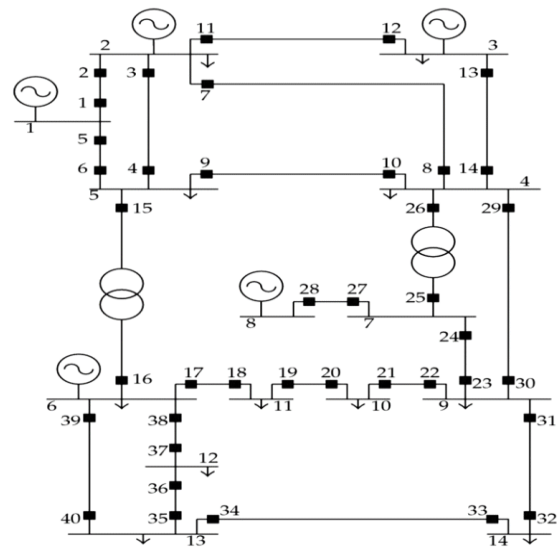


Fig. 11. Single line diagram of IEEE standard 14 bus test system.

TABLE VI.    ANALYSIS OF 14 BUS, 40 RELAYS TEST SYSTEM FOR DIFFERENT OPTIMIZATION ALGORITHMS

| Relay Number | Relay Operating Time (sec) | | | |
|---|---|---|---|---|
| | Cuckoo Search Algorithm | Fire-fly Algorithm | Harmony Search Algorithm | Jaya Algorithm |
| 1 | 0.3464 | 0.2263 | 0.1016 | 0.0826 |
| 2 | 0.2205 | 0.2574 | 0.1112 | 0.0844 |
| 3 | 0.3156 | 0.3541 | 0.3101 | 0.1058 |
| 4 | 0.4366 | 0.3682 | 0.1320 | 0.0625 |
| 5 | 0.6594 | 0.5110 | 0.0901 | 0.1291 |
| 6 | 0.3882 | 0.2740 | 0.1640 | 0.0512 |
| 7 | 0.2874 | 0.2543 | 0.0625 | 0.0362 |
| 8 | 0.5520 | 0.5269 | 0.2390 | 0.1063 |
| 9 | 0.6306 | 0.5141 | 0.2875 | 0.1023 |
| 10 | 0.4336 | 0.4079 | 0.3344 | 0.1155 |
| 11 | 0.8722 | 0.3813 | 0.2873 | 0.2630 |
| 12 | 0.5683 | 0.3433 | 0.0215 | 0.0585 |
| 13 | 0.3235 | 0.2981 | 0.1050 | 0.0970 |
| 14 | 0.3297 | 0.3058 | 0.1847 | 0.0643 |
| 15 | 0.3934 | 0.3663 | 0.1986 | 0.0666 |
| 16 | 0.2905 | 0.2874 | 0.1112 | 0.0844 |
| 17 | 0.3176 | 0.2341 | 0.1601 | 0.0658 |
| 18 | 0.2926 | 0.1682 | 0.0320 | 0.0042 |
| 19 | 0.2394 | 0.2110 | 0.0901 | 0.1291 |
| 20 | 0.3506 | 0.2340 | 0.2315 | 0.2512 |
| 21 | 0.4360 | 0.3543 | 0.1025 | 0.0894 |
| 22 | 0.2596 | 0.2269 | 0.2390 | 0.1163 |
| 23 | 0.1236 | 0.1941 | 0.0875 | 0.0768 |
| 24 | 0.3365 | 0.4079 | 0.1344 | 0.0555 |
| 25 | 0.4692 | 0.3813 | 0.2173 | 0.1630 |
| 26 | 0.3695 | 0.3433 | 0.2015 | 0.1385 |
| 27 | 0.2235 | 0.2181 | 0.1450 | 0.0970 |
| 28 | 0.3296 | 0.3058 | 0.1847 | 0.0643 |
| 29 | 0.3342 | 0.2363 | 0.2186 | 0.0026 |
| 30 | 0.3369 | 0.2874 | 0.1112 | 0.0844 |
| 31 | 0.2365 | 0.2251 | 0.0601 | 0.0558 |
| 32 | 0.2125 | 0.1682 | 0.1320 | 0.0642 |
| 33 | 0.3265 | 0.2110 | 0.1901 | 0.1291 |
| 34 | 0.2785 | 0.1740 | 0.1315 | 0.0512 |
| 35 | 0.3696 | 0.2543 | 0.2025 | 0.0694 |
| 36 | 0.2365 | 0.2269 | 0.2390 | 0.1163 |
| 37 | 0.2874 | 0.3141 | 0.2875 | 0.2768 |
| 38 | 0.3355 | 0.2379 | 0.1334 | 0.1155 |
| 39 | 0.4364 | 0.3813 | 0.3173 | 0.2630 |
| 40 | 0.3652 | 0.3433 | 0.2415 | 0.1385 |
| $Z_{min}$ | 8.3655 | 8.2506 | 4.5636 | 3.0454 |

The base MVA for calculating sequence currents is taken 500 MVA to construct zero sequence, positive sequence and negative sequence networks. The short circuit computation is completed with a conservative load flow analysis based on those sequence networks, at all fault points. Primary and backup protective relay pairs are recognized, and based on fault locations it is located in the system.
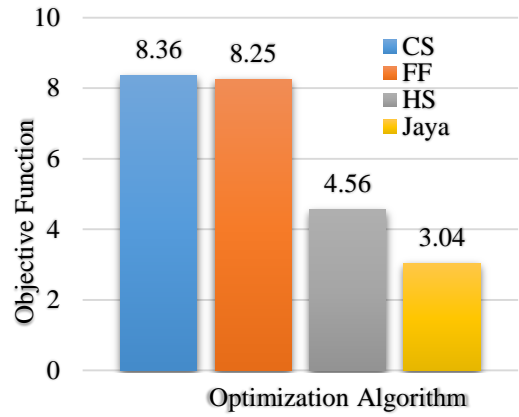


Fig. 12.  Objective function values for various optimization technique for 14 bus test system.

Comparative valuation of the different present algorithms and the proposed Jaya algorithm is shown in Table VI. The output is shown in terms of relay tripping time and total operating time for primary protective relays given by some different algorithms. Minimum and maximum operating time limit has been set to 0.5 sec and 1 sec respectively. The number of iterations would be same for all algorithms and is taken 100 iterations. The population size is taken 10 for Jaya algorithm. Fig. 12 shows the comparative analysis chart of the 14 bus, 40 relays test system along their objective function results and respective optimization techniques.

TABLE VII.    STATISTICALLY ANALYSIS OF 14 BUS, 40 RELAYS TEST SYSTEM

| Parameter | CSA | FFA | HSA | JA |
|---|---|---|---|---|
| Mean | 0.3638 | 0.3004 | 0.1708 | 0.1032 |
| Standard Deviation | 0.1387 | 0.09275 | 0.08119 | 0.06420 |
| 95% CI for the mean | 0.3194 to 0.4081 | 0.2707 to 0.3300 | 0.1448 to 0.1967 | 0.08266 to 0.1237 |
| Standard error of the mean | 0.02193 | 0.01466 | 0.01284 | 0.01015 |

The standard deviation and the standard error of the mean as shown in Table VII are 0.02193, 0.01466, 0.01284 and 0.01015 obtained by CSA, FFA, HSA and Jaya algorithm. From this table, it can be observed that the best value of standard deviation error is minimum (0.01015 sec) is obtained by Jaya which is the least value compared to the other techniques. This means that the Jaya algorithm gives the lowest standard deviation (0.01015 sec).

*D. Analysis of 30-Bus, 42 Relays Test System Network*

The single line diagram of IEEE 30-bus test network is shown in Fig. 13 [13], contains 42 relays.

The short-circuit data are taken from the test data set. In this network, the system has 4 generators, 21 transmission lines and it is fed through 4 generators, two transformers $T_1$ and $T_2$. The range of TDS is set to be in between 0.5 sec to 1 sec for all the algorithms. The CT ratio is considered as 500/1 A for all the relays.
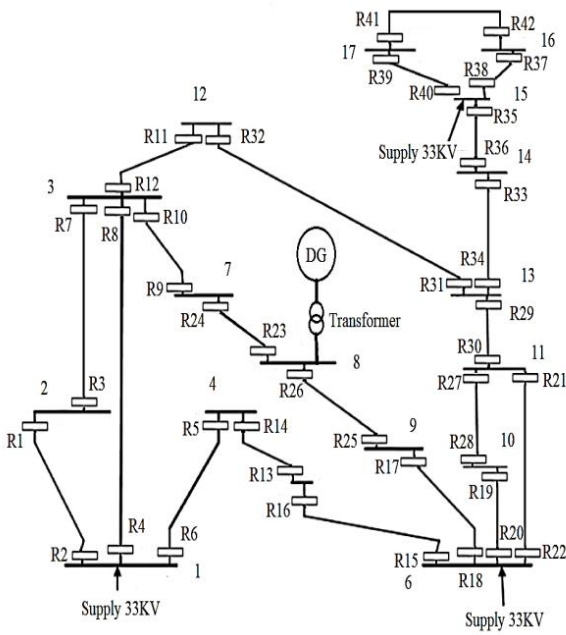
Fig. 13. Single line diagram of IEEE standard 30 bus test system.

Comparative valuation of the different present algorithms and the proposed Jaya algorithm is shown in Table VIII. The output is shown in terms of relay tripping time and total operating time for primary protective relays given by some different algorithms. Minimum and maximum operating time limit has been set to 0.5 sec and 1 sec respectively. The number of iterations would be same for all algorithms and is taken 100 iterations.

TABLE VIII. ANALYSIS OF 30 BUS, 42 RELAYS TEST SYSTEM FOR DIFFERENT OPTIMIZATION ALGORITHMS

| Relay Number | Relay Operating Time (sec) | | | |
|---|---|---|---|---|
| | Cuckoo Search Algorithm | Fire-fly Algorithm | Harmony Search Algorithm | Jaya Algorithm |
| 1 | 0.3364 | 0.1263 | 0.0516 | 0.0526 |
| 2 | 0.1205 | 0.1874 | 0.1112 | 0.0844 |
| 3 | 0.4156 | 0.3541 | 0.3101 | 0.1058 |
| 4 | 0.2366 | 0.1682 | 0.1320 | 0.0525 |
| 5 | 0.1594 | 0.2110 | 0.0901 | 0.1291 |
| 6 | 0.2882 | 0.0740 | 0.1640 | 0.0512 |
| 7 | 0.2574 | 0.1543 | 0.0625 | 0.0662 |
| 8 | 0.4320 | 0.3269 | 0.2390 | 0.0563 |
| 9 | 0.2906 | 0.3141 | 0.2875 | 0.1023 |
| 10 | 0.4336 | 0.4079 | 0.3344 | 0.1155 |
| 11 | 0.3722 | 0.3813 | 0.2873 | 0.2630 |
| 12 | 0.3683 | 0.3433 | 0.0615 | 0.0585 |
| 13 | 0.3235 | 0.2981 | 0.1050 | 0.0970 |
| 14 | 0.3297 | 0.3058 | 0.1847 | 0.0643 |
| 15 | 0.3934 | 0.2063 | 0.1986 | 0.0766 |

| 16 | 0.2905 | 0.2874 | 0.1112 | 0.0844 |
|---|---|---|---|---|
| 17 | 0.3176 | 0.2341 | 0.1601 | 0.0658 |
| 18 | 0.1926 | 0.0682 | 0.0620 | 0.0542 |
| 19 | 0.2394 | 0.2110 | 0.0901 | 0.1291 |
| 20 | 0.3506 | 0.1340 | 0.2315 | 0.2512 |
| 21 | 0.4360 | 0.3543 | 0.1025 | 0.0594 |
| 22 | 0.2596 | 0.2269 | 0.2390 | 0.1163 |
| 23 | 0.1236 | 0.1941 | 0.0875 | 0.0768 |
| 24 | 0.3365 | 0.4079 | 0.1344 | 0.0555 |
| 25 | 0.4692 | 0.3813 | 0.2173 | 0.1630 |
| 26 | 0.3695 | 0.3433 | 0.2015 | 0.1385 |
| 27 | 0.2235 | 0.2181 | 0.1450 | 0.0970 |
| 28 | 0.3296 | 0.3058 | 0.1847 | 0.0643 |
| 29 | 0.3342 | 0.2363 | 0.2186 | 0.0506 |
| 30 | 0.3369 | 0.2874 | 0.1112 | 0.0844 |
| 31 | 0.2365 | 0.2251 | 0.0601 | 0.0558 |
| 32 | 0.2125 | 0.1682 | 0.1320 | 0.0542 |
| 33 | 0.3265 | 0.2110 | 0.1901 | 0.1291 |
| 34 | 0.2785 | 0.1740 | 0.1315 | 0.0512 |
| 35 | 0.3696 | 0.2543 | 0.2025 | 0.0194 |
| 36 | 0.2365 | 0.2269 | 0.2390 | 0.1163 |
| 37 | 0.2874 | 0.3141 | 0.2875 | 0.2768 |
| 38 | 0.3355 | 0.2379 | 0.1334 | 0.1155 |
| 39 | 0.4364 | 0.3813 | 0.3173 | 0.2630 |
| 40 | 0.3652 | 0.3433 | 0.2415 | 0.1385 |
| 41 | 0.2874 | 0.2781 | 0.3150 | 0.0970 |
| 42 | 0.3125 | 0.3058 | 0.2747 | 0.0643 |
| $Z_{min}$ | 9.6204 | 8.3520 | 5.5230 | 4.1308 |
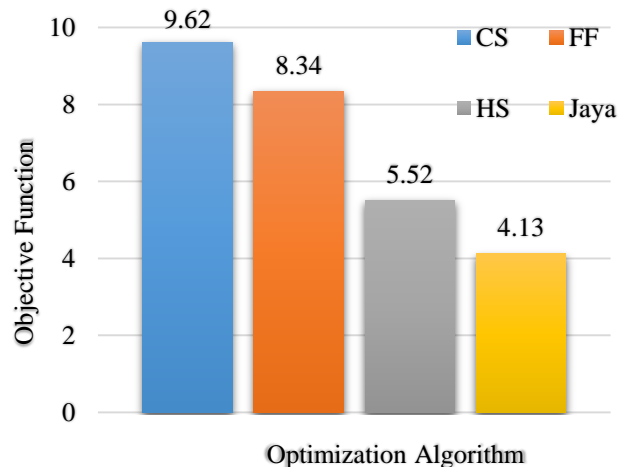


Fig. 14. Objective function values for various optimization techniques for 30 bus test system.

Fig. 14 shows the comparative analysis chart of the 30 bus, 42 relays test system along their objective function results and respective optimization techniques.

TABLE IX. STATISTICALLY ANALYSIS OF 30 BUS, 42 RELAYS TEST SYSTEM

| Parameter | CSA | FFA | HSA | JA |
|---|---|---|---|---|
| Mean | 0.3107 | 0.2588 | 0.1772 | 0.1011 |
| Standard Deviation | 0.08308 | 0.08744 | 0.08243 | 0.06194 |
| 95% CI for the mean | 0.2849 to 0.3366 | 0.2194 to 0.3058 | 0.1515 to 0.2028 | 0.08181 to 0.1204 |
| Standard error of the mean | 0.01282 | 0.01349 | 0.01272 | 0.009558 |

The standard deviation and the standard error of the mean as shown in Table IX are 0.08308, 0.08744, 0.08243 and 0.06194 obtained by CSA, FFA, HSA and Jaya algorithm. From the above table, it can be observed that the best value of standard deviation error is minimum (0.06194sec) is obtained by Jaya which is the least value compared to the other techniques. This means that the Jaya algorithm gives the lowest standard deviation (0.06194sec).

The results obtained from different optimization algorithms along the proposed Jaya algorithm using conventional relay characteristic are shown in Table IX. The aim of the relay coordination optimization is to reduce the total operating time of all protective devices. Table shows the operating time of each relays, which can be comparable with the result from different algorithms. The value of objective function has to be minimized for relay coordination problem. Proposed Jaya algorithm gives the best result among other algorithms. The evaluation time for each algorithm is different as per their parameters and number of populations.

TABLE X. COMPARATIVE ANALYSIS OF RESULTS OBTAINED FROM DIFFERENT ALGORITHMS

| Relay System | Value of Objective Function (sec) | | | |
|---|---|---|---|---|
| | CS | FF | HS | Jaya |
| 10 relay system | 3.39 | 3.31 | 1.52 | 1.33 |
| 14 relay system | 3.42 | 3.30 | 1.35 | 1.15 |
| 40 relay system | 8.36 | 8.25 | 4.56 | 3.04 |
| 42 relay system | 9.62 | 8.34 | 5.52 | 4.13 |

Table IX shows the comparative analysis with optimized results of different optimization algorithms used for relay coordination optimization problem for four different test systems.

TABLE XI. STATISTICAL ANALYSIS OF OBJECTIVE FUNCTION

| Parameter | CSA | FFA | HSA | JA |
|---|---|---|---|---|
| Mean | 6.1975 | 5.8000 | 3.2375 | 2.4125 |
| Standard Deviation | 3.2653 | 2.8812 | 2.1191 | 1.4270 |
| 95% CI for the mean | 1.0017 to 11.3933 | 1.2153 to 10.3847 | -0.1344 to 6.6094 | 0.1418 to 4.6832 |
| Standard error of the mean | 1.6326 | 1.4406 | 1.0595 | 0.7135 |

The standard deviation and the standard error of the mean as shown in Table X are 1.6326, 1.4406, 1.0595 and 0.7135

obtained by CSA, FFA, HSA and Jaya algorithm. From this table, it can be observed that the best value of standard deviation error is minimum (0.7135 sec) is obtained by Jaya which is the least value compared to the other techniques. This means that the Jaya algorithm gives the lowest standard deviation (0.7135 sec).

Performance of the Jaya algorithm as the optimization tool for relay coordination operating time for different test systems has been evaluated. It has been observed that, the total sum of operating time of all the protective relays is given by the Jaya algorithm may be changed with the different evaluation, the number of constraints increases the overall evaluation time. It is also seen that some of relay TDS has been changed according to their parameters and limits of fitness, it would not much affect the overall operating time for relay coordination. It should be pointed that, the total operating time of all protective relays, is higher and for fault point at far-end when the fault is at the middle point, it is highest as compared to fault point at near-end, the proposed Jaya algorithm gives most appropriate results without any unbalanced operation of relays. It should also to be pointed that for the primary relays, relay operating time will rises as the change in the position of fault from near end to far end of the distributed feeders. The results undoubtedly indicate that the Jaya algorithm gives best optimum result as compare to the other algorithm used in relay coordination optimization.

## VI. CONCLUSION

In this study, we have successfully developed and implemented a novel approach to optimizing power management in distribution networks through the coordination of directional over-current relays. Through our work, we have achieved several significant outcomes. First and foremost, we have demonstrated a practical and effective mathematical modeling approach that accounts for the dynamic nature of distribution networks, enabling precise and adaptive relay coordination. Our algorithm has shown promising results in terms of enhancing the reliability of distribution networks, significantly reducing downtime during faults, and improving the overall safety of the power grid.

The proper tuning of the algorithm specific parameters is a very crucial factor which affects the performance of the above mentioned algorithms. The improper tuning of algorithm specific parameters either increases the computational effort or yields the local optimal solution. The four different test systems are considered. The execution of each algorithm has been set to 100 iterations keeping the initial conditions as same for all the four test systems as considered in our test system. Jaya algorithm is considered as best one among the four algorithms based on the results obtained in the work. Jaya algorithm is found to be very efficient as we can see that the variation in the solutions on the reaching towards the optima. It should be noted that the total operating time of all protective relays is higher for fault point at far-end; when the fault is at the middle point, it is highest as compared to fault point at near-end; thus, the proposed Jaya algorithm gives most appropriate results without any unbalanced operation of relays in the distribution systems. It should also to be pointed that for the primary relays, relay operating time will rises as the change

in the position of fault from near end to far end of the distributed feeders.

## REFERENCES

[1] P. P. Bedekar, S. R. Bhide, and V. S. Kale, "Optimum coordination of overcurrent relays in distribution system using genetic algorithm," 2009 Int. Conf. Power Syst. ICPS '09, pp. 25–30, 2009, doi: 10.1109/ICPWS.2009.5442716.

[2] S. S. Gokhale and V. S. Kale, "Time overcurrent relay coordination using the Levy flight Cuckoo search algorithm," IEEE Reg. 10 Annu. Int. Conf. Proceedings/TENCON, vol. 2016-Janua, pp. 1–6, 2016, doi: 10.1109/TENCON.2015.7372879.

[3] R. Mohammadi Chabanloo, H. Askarian Abyaneh, S. S. Hashemi Kamangar, and F. Razavi, "Optimal combined overcurrent and distance relays coordination incorporating intelligent overcurrent relays characteristic selection," IEEE Trans. Power Deliv., vol. 26, no. 3, pp. 1381–1391, 2011, doi: 10.1109/TPWRD.2010.2082574.

[4] P. A. Bangar et al., "Optimal Overcurrent Relay Coordination Using Optimized Objective Function," ISRN Power Eng., vol. 2, no. 3, pp. 1–10, 2018, doi: 10.1155/2014/869617.

[5] J. M. Ghogare and V. N. Bapat, "Field based case studies on overcurrent relay coordination optimization using GA-NLP approach," 2015 IEEE Int. Conf. Electron. Comput. Commun. Technol. CONECCT 2015, pp. 1–6, 2016, doi: 10.1109/CONECCT.2015.7383894.

[6] D. S. Nair and S. Reshma, "Optimal coordination of protective relays," Proc. 2013 Int. Conf. Power, Energy Control. ICPEC 2013, pp. 239–244, 2013, doi: 10.1109/ICPEC.2013.6527658.

[7] T. Khurshaid, A. Wadood, S. G. Farkoush, C. H. Kim, N. Cho, and S. B. Rhee, "Modified Particle Swarm Optimizer as Optimization of Time Dial Settings for Coordination of Directional Overcurrent Relay," J. Electr. Eng. Technol., vol. 14, no. 1, pp. 55–68, 2019, doi: 10.1007/s42835-018-00039-z.

[8] C. A. Castillo, A. Conde, and M. Y. Shih, "Improvement of non-standardized directional overcurrent relay coordination by invasive weed optimization," Electr. Power Syst. Res., vol. 157, pp. 48–58, 2018, doi: 10.1016/j.epsr.2017.11.014.

[9] Z. Moravej and O. Soleimani Ooreh, "Coordination of distance and directional overcurrent relays using a new algorithm: Grey Wolf optimizer," Turkish J. Electr. Eng. Comput. Sci., vol. 26, no. 6, pp. 3130–3144, 2018, doi: 10.3906/elk-1803-123.

[10] A. Korashy, S. Kamel, A. R. Youssef, and F. Jurado, "Modified water cycle algorithm for optimal direction overcurrent relays coordination," Appl. Soft Comput. J., vol. 74, pp. 10–25, 2019, doi: 10.1016/j.asoc.2018.10.020.

[11] A. S. Noghabi, H. R. Mashhadi, and J. Sadeh, "Optimal coordination of directional overcurrent relays considering different network topologies using interval linear programming," IEEE Trans. Power Deliv., vol. 25, no. 3, pp. 1348–1354, 2010, doi: 10.1109/TPWRD.2010.2041560.

[12] A. J. Urdaneta, R. Nadira, and L. G. Pérez Jiménez, "Optimal Coordination of Directional Overcurrent Relays in Interconnected Power Systems," IEEE Trans. Power Deliv., vol. 3, no. 3, pp. 903–911, 1988, doi: 10.1109/61.193867.

[13] K. A. Saleh, H. H. Zeineldin, and A. Al-Hinai, "A three-phase fault currents calculation method used for protection coordination analysis," Proc. IEEE Power Eng. Soc. Transm. Distrib. Conf., 2014, doi: 10.1109/tdc.2014.6863444.

[14] I. N. Trivedi, S. V. Purani, and P. K. Jangir, "Optimized over-current relay coordination using Flower Pollination Algorithm," Souvenir 2015 IEEE Int. Adv. Comput. Conf. IACC 2015, pp. 72–77, 2015, doi: 10.1109/IADCC.2015.7154671.

[15] G. U. Darji, M. J. Patel, V. N. Rajput, and K. S. Pandya, "A tuned cuckoo search algorithm for optimal coordination of Directional Overcurrent Relays," Proc. 2015 IEEE Int. Conf. Power Adv. Control Eng. ICPACE 2015, no. 1, pp. 162–167, 2015, doi: 10.1109/ICPACE.2015.7274936.

[16] A. J. Urdaneta and L. G. Pérez Jiménez, "Optimal coordination of directional overcurrent relays considering definite time backup relaying," IEEE Trans. Power Deliv., vol. 14, no. 4, pp. 1276–1284, 1999.

[17] R. V. Rao and G. G. Waghmare, "A new optimization algorithm for solving complex constrained design optimization problems," Eng. Optim., vol. 49, no. 1, pp. 60–83, 2017, doi: 10.1080/0305215X.2016.1164855.

[18] P. P. Bedekar and P. N. Korde, "Optimum coordination of overcurrent relays using the modified Jaya algorithm," 2016 IEEE Uttar Pradesh Sect. Int. Conf. Electr. Comput. Electron. Eng. UPCON 2016, pp. 479–484, 2017, doi: 10.1109/UPCON.2016.7894701.

[19] M. Singh, B. K. Panigrahi, and A. R. Abhyankar, "Optimal coordination of directional over-current relays using Teaching Learning-Based Optimization (TLBO) algorithm," Int. J. Electr. Power Energy Syst., vol. 50, no. 1, pp. 33–41, 2013, doi: 10.1016/j.ijepes.2013.02.011.

[20] S. Ralhan and S. Ray, "Directional overcurrent relays coordination using linear programming intervals: A comparative analysis," 2013, doi: 10.1109/INDCON.2013.6725883.

[21] M. Zellagui and H. A. Hassan, "A Hybrid Optimization Algorithm ( IA-PSO ) for Optimal Coordination of Directional Overcurrent Relays in Meshed Power Systems 2 Optimal Problem Relay Coordination," vol. 10, no. October, pp. 240–250, 2015.

# Implementation of the REST API Model using QR Codes on Mobile Devices to Order Parking Tickets

Mauluddini Amras[1], Erwin Yulianto[2], Deshinta Arrova Dewi[3], Awan Setiawan[4]

Department of Informatics, Faculty of Engineering, Langlangbuana University, Bandung, Indonesia[1, 2, 4]
Faculty of Data Science and Information Technology-INTI International University, Nilai, Malaysia[1, 3]

*Abstract*—Many parking lots are still operate manually, and delays are commonly caused during the parking process when unforeseen events occur, such as when the parking ticket paper runs out or the ticket machines jam. New services are added to the parking system online with the aim of decreasing the amount of time that people spend waiting in line to park. This is done by conducting a parking booking system to obtain a parking ticket in the form of a QR Code as well as parking information, payment transactions, and other things that interfere with the parking process. In this study, the Forward Chaining Algorithm will be combined with the survey research method as the research methodology. The Rapid Application Development model is used for analysis and design (RAD). Representational State Transfer Application Programming Interface (REST API) is one of the solutions offered to overcome this problem. With the advent of online parking services, it is envisioned that customers who intend to park their vehicles in public spaces will be able to reserve a parking space in advance, greatly simplifying the process and eliminating the problem of the drawn out queue process.

*Keywords—Representational state transfer application programming interface (REST API); online parking ticket; quick response code (QR Code); smart city; public transport*

## I. INTRODUCTION

Parking service is one of the services in the field of services, where parking is almost available in all places, shopping centers, schools, and is also available on the side of the road. Parking is a necessity for vehicle owners and wants their vehicles to be parked in a place, where the place is easy to reach [1]. In Indonesia, having a place to store vehicles (parking lots) when visiting a place for shopping, playing, and other activities is a place that must be available.

Often the process of parking the vehicle will cause a queue if unwanted things such as the parking ticket paper run out, the ticket machine is jammed and other things will result in a long queue during the parking process. Determination of location and construction of parking facilities for the public is carried out by taking into account the general design of regional spatial planning, safety and smooth traffic, environmental sustainability, and convenience for service users [2]. However, currently there are still many parking places that use manual habits, namely after arriving at the parking lot, then pressing the button for a ticket and then entering the parking area and looking for a place to park. In addition, there are often long queues due to system errors, running out of ticket paper, and processing queues during the payment process.

Based on the preliminary description above, it can be concluded that several problem points that are the purpose of this activity include providing information and providing easy parking processes for users who will do parking. In addition, it also anticipates problems in the vehicle parking process such as the problem of running out of parking tickets, jammed ticket machines that can prolong the parking queue. Based on the preliminary description, this research aims to address several problem points, including:

*1)* Providing accessible information and streamlining the parking process for users.

*2)* Anticipating and preventing common issues encountered during the vehicle parking process, such as ticket shortages and queue delays.

The research problem revolves around the need for a more efficient and convenient parking experience, particularly in regions where parking services frequently face issues like long queues and technical disruptions. These problems stem from traditional, manual parking processes that may not align with modern expectations and urban development. The research seeks to answer the following questions:

*1)* How can the parking experience be improved for users?

*2)* What are the specific challenges associated with traditional parking processes?

*3)* How can the implementation of the REST API and QR Code technology enhance parking services?

The research objectives include:

*1)* To streamline the parking process, making it more user-friendly and efficient.

*2)* To identify and address common challenges in the existing parking systems.

*3)* To demonstrate the advantages of implementing the REST API and QR Code technology in the context of parking services.

This research is significant because it presents a solution to common issues encountered in parking services while aligning with the broader Smart City ecosystem. By implementing the REST API and QR Code technology, it seeks to enhance the parking experience for users, reduce queue times, and contribute to the efficiency and sustainability of urban transportation. The primary contribution of this research is the innovative application of REST API in online ticket ordering using mobile device QR Codes, offering a solution that

enhances the efficiency and convenience of parking services within the Smart City ecosystem. This contribution addresses issues commonly encountered in parking processes and aligns with modern urban development goals. The novelty that is unique in this research is the application of the REST API in ordering tickets online using a mobile device QR Code, which is part of one of the solutions in the Smart City ecosystem.

## II. LITERATURE REVIEW

### A. Representation State Transfer Application Programming Interface

In 2000, after the Web scalability crisis was averted, Fielding named and described the Web architectural style with a Ph. on. Web services are custom built web servers that support the needs of other sites or applications. Client programs use the Application Programming Interface (API) to communicate with web services. In general, an API provides a set of data and functions to facilitate interaction between computer programs and allow them to exchange information as shown in Fig. 1[3]:
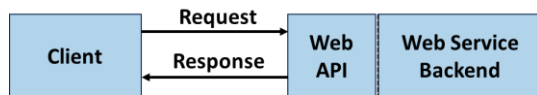


Fig. 1. Data request process [3].

As it can be seen in Fig. 1 above, there is a web service system, the web service itself is a software system that is intended as a liaison for interaction between machines and other machines in a system [4].

Web APIs are the face of web services, listening directly to and responding to client requests. The REST architectural style is generally applied to the design of APIs for modern web services. The web API that fits the REST architectural style is the REST API. Having a REST API makes a web service "RESTful". REST APIs consist of a collection of interrelated resources. This collection of resources is known as the REST API resource model. A well designed REST API can attract client developers to use web services. In today's open market where competing web services compete for attention, an aesthetically pleasing REST API design is a must have feature [3], [13].

### B. Ticket

The ticket is an important document that must be owned by passengers who will make a trip, the document is issued by the company or related body that acts as the owner of the services offered [5]. By having a ticket, a person will get services on land, sea and air transportation, both domestic and international. However, if this ticket is not used in whole or only part of the routes listed on the ticket, it can be cashed back according to the agreed agreement. Some of the ticket types used to date is as follows [6]:

- Ticket Paper Manual is a ticket made of valuable paper/document in the form of a book which is issued by writing using a pen. This ticket, although it has been used for a long time, is still used by several airlines. The ticket book is printed on special paper so that it is not

easily counterfeited. There are audit coupons, agent coupons and passenger coupons that are useful as control over the issuance of a ticket.

- Ticket paper printers are those made of valuable paper/documents in the form of books issued by printing using a printer that is operated with a certain ticketing system. One ticket book consists of four flight coupons, audit coupons, agent coupons and passenger coupons.

- Electronic ticket is a ticket made electronically, where all flight and passenger data written in it are stored in an electronic document in the airline database or ticketing system Provider Company. Passengers only need to bring a printout of the data which can be reprinted repeatedly.

### C. Park

Based on the results of studies in Guidelines for Planning and Operation of Parking Facilities, measuring space requirements Parking at activity centers is determined according to the nature and purpose of the parking. In practice in the field, it must be adjusted to parking demand every type of vehicle [12].

Every trip using a vehicle begins and ends at the parking lot, therefore parking spaces are spread out at the origin of the trip, which can be in the car garage, yard, roadside, and the destination of the trip, in the parking lot, parking building or on the side of the road. Because the concentration of the destination of the trip is higher than the place of origin of the trip, it usually becomes a problem at the destination of the trip. Parking is a temporary state of immobility of a vehicle, while stopping is a temporary state of immobility of a vehicle with the driver not leaving the vehicle [7]:

- Parking tariff policy is determined based on location and time, the closer to the City activities the higher the tariff, the higher the higher the rate. This policy is directed at controlling the number of parkers in the city center or activity center and encouraging the use of public transportation.

- Parking space restriction policy, especially in the downtown area or activity center. This policy is usually carried out on roadside parking whose main purpose is to smooth traffic flow, as well as restrictions on offstreet parking spaces which are carried out through IMB (Building Permits).

- Strict law enforcement policies against violators of the provision that parking is prohibited and prohibited from stopping and parking outside the designated place for this purpose, law enforcement can be carried out through fines or with wheel locks.

### D. Quick Response Code

Since its introduction in 1994, the QR Code has gained widespread acceptance in various industries such as manufacturing, warehousing and logistics, retail, healthcare, life sciences, transportation, and office automation. Now with the tremendous growth of smartphones, QR Codes are also

being used in mobile marketing and advertising campaigns as a fast and effective way to connect with customers and provide end user content, including Web links, mobile coupons, airline boarding passes, etc. Successful implementation of QR Code in any of these fields requires knowledge of certain basic information about the QR Code itself and the technology associated with it. Although the QR Code was originally designed to track automotive components and systems through the manufacturing process and distribution supply chain, it quickly spread to almost every other area where traditional barcodes are used, as well as some entirely new ones [8]. The following is an example of the display of the QR Code which can be seen in Fig. 2.



Fig. 2.   QR code [8].

A QR Code (Quick Response Code) is a two dimensional (2D) matrix code belonging to a larger set of machine readable codes, all of which are often referred to as barcodes, regardless of whether they consist of bars, squares or other shaped elements. Compared to 1 D code, 2 D can hold a larger amount of data in a smaller space, and compared to other 2 D codes, QR Code can store more data. In addition, advanced error correction methods and other unique characteristics allow QR Codes to be read more reliably and at a higher speed than other codes. Like written language, barcodes are a visual representation of information. Unlike languages, however, which can be read by humans, barcodes are designed to be read and understood (decoded) by a computer, using a machine vision system consisting of an optical laser scanner or camera and barcode interpretation software. The rules used to create barcodes (grammar) and the characters they use (the alphabet) are called symbology [8].



Fig. 3.   QR code vs. barcode [8].

Unlike 1 D barcodes, QR Codes are 2D matrix codes that convey information not based on the size and position of the bars as seen in Fig. 3 above and spaced in one dimension (horizontal), but by arrangement of dark and light elements, called "modules"., in columns and rows, i.e. in both horizontal and vertical directions. Each dark or light module of a QR Code symbol a specific example of a code represents a 0 or 1, thus making it machine understandable [8].

QR Code modules perform several functions, some contain the actual data itself, while others are grouped into various function patterns that improve reading performance and allow

symbol alignment, error correction, and distortion compensation. The timing pattern allows the scanning device to know the symbol size. There is also a required "quiet zone", a buffer area four modules wide that contains no data, to ensure that the text or creation area is not mistaken for QR Code data. The function pattern on the QR Code can be seen in Fig. 4 below.
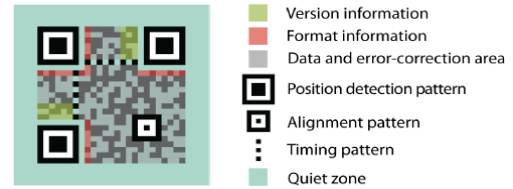


Fig. 4.   QR code function pattern [8].

Conventional 2D matrix codes require a lot of time to search for symbol codes to determine orientation angle, position (x and y coordinates), and size. To solve this problem, the QR Code was designed with a special position detection pattern located at the three corners of each symbol. The patterns have a 1:1:3:1:1 symmetric scan line ratio, which allows them to be scanned from any direction in a full 360 degrees. In addition, pattern position relationships allow quick access to relevant angle, position, and size information contained in the periphery of the code. As a result, QR Codes do not require lengthy code searches, enabling read speeds up to 20 times faster than conventional matrix codes. The position detection pattern search process can be performed by the scanning hardware, further increasing the overall speed by allowing image reading and data processing to be performed simultaneously [8].

Developing Android applications for a Parking Information System using Adobe AIR involves creating a mobile app that provides users with real-time parking information, such as available parking spots, pricing, location details, and navigation assistance. Adobe AIR is a cross-platform runtime that allows developers to build applications using web technologies like HTML, JavaScript, and ActionScript. [14]

A comprehensive review of the research entitled "Implementation of the REST API Model Using QR Codes on Mobile Devices to Order Parking Tickets" will include an understanding of the REST API concept, parking ticket ordering, and the use of QR Codes in the context of mobile applications. This research focuses on applying the REST API concept, ordering parking tickets, and using QR codes to create a solution that makes it easier to order parking tickets via mobile devices. This can improve user experience and efficiency in parking management, as well as utilize modern technology to overcome challenges in urban transportation and parking management.

## III.  RESEARCH METHOD

This section may be divided by subheadings. It should provide a concise and precise description of the experimental results, their interpretation, as well as the experimental conclusions that can be drawn.

### A. Data Collection Stage

The data collection stage was carried out with the Literature Study stage, carried out by searching for information from books, e-books, websites, modules, journals, internet browsing and various other literature related to making the Forward Chaining algorithm application. Next is the observation method or observation is direct observation, which is an activity that aims to obtain the necessary information by observing and recording and reviewing.

### B. System Development Stage

The stages of system development used in this application are the Rapid Application Development (RAD) model, with black box testing. The stages of the Rapid Application Development (RAD) method can be seen in Fig. 5 below:
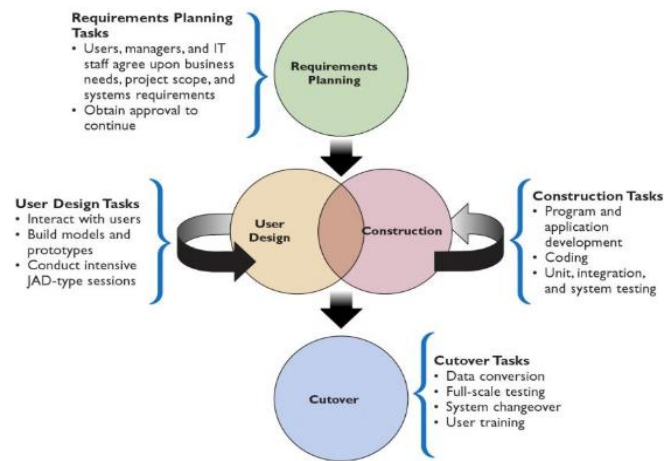


Fig. 5. RAD phases [9].

The explanation of these stages can be seen in the following points: [10].

*1) Requirements planning*: The requirements planning phase combines elements of the systems planning and systems analysis phases of the SDLC. Users, managers, and IT staff members discuss and agree on business requirements, project scope, constraints, and system requirements. The requirements planning phase ends key issues and obtains management's permission to continue.

*2) User design*: During the user design phase, the user interacts with the systems analyst and develops models and prototypes that represent all system processes, outputs, and inputs. RAD groups or subgroups typically use a combination of JAD techniques and CASE tools to translate user requirements into a working model. User design is an interactive and continuous process that allows users to understand, modify, and ultimately agree on a system working model that meets their needs.

*3) Construction*: The construction phase focuses on the tasks of developing programs and applications that are similar to the SDLC. However, in RAD, users continue to participate and can still suggest changes or improvements as the actual screen or report is developed.

*4) Cutover*: The transition phase resembles the final tasks in the SDLC implementation phase, including data conversion, testing, switching to the new system, and user training. Compared with traditional methods, the whole process is compressed. As a result, new systems are built, shipped, and put into operation more quickly.

The Software Development Method using the RAD (Rapid Application Development) model has several advantages compared to other software development methods, especially in the context of project-based software development which requires flexibility, speed and high response to changing needs. Here are some of the advantages of RAD:

*1) Rapid development*: As the name suggests, RAD emphasizes on rapid development. In this model, the main focus is to produce a usable prototype or application quickly.

*2) High customer engagement*: RAD promotes active customer or stakeholder engagement.

*3) Flexibility*: The RAD model is very flexible and can handle changing requirements well.

*4) Better quality*: Through repeated iterations, RAD allows teams to identify and address problems earlier in the development cycle.

*5) Emphasis on reusability*: RAD encourages reusable component-based development that can save time and effort in subsequent project development.

*6) Cost efficiency*: While there are initial costs associated with developing a prototype, long-term savings can be achieved due to the reduction in changes that must be made in later stages of the project.

*7) Suitability for small-medium projects*: The RAD method is generally better suited for small to medium sized projects that require quick updates or upgrades.

*8) Concentrate on key functionality*: RAD focuses on the key functionality required by customers, avoiding features that may be unnecessary or annoying.

*9) Risk reduction*: By having prototypes that can be tested and evaluated, project risks can be reduced as problems can be identified early.

*10) Improved team collaboration*: RAD encourages active collaboration among development team members and stakeholders. This can result in a better understanding of needs and desired solutions.

In addition to the system development method using the Rapid Application Development (RAD) method, this study also uses Unified Modeling Language (UML) Diagrams as a tool in the analysis process and also in system design.

## IV. RESULT AND DISCUSSION

### A. Business Process Analysis

Based on the results of the data collection stages, the business processes in this research activity can be seen in the flowmap in Fig. 6 to Fig. 9 below:
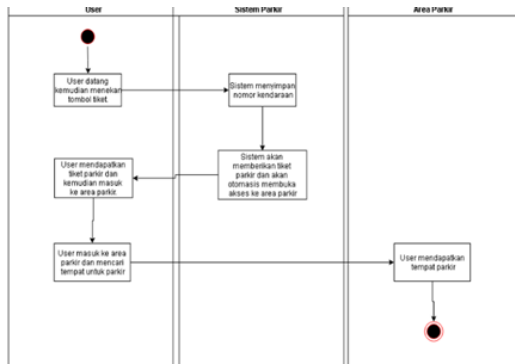
Fig. 6.  Business process runs from manual parking entry process.
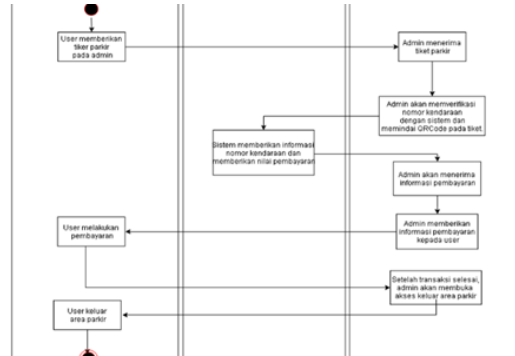


Fig. 7.  Business process running from manual parking exit process.
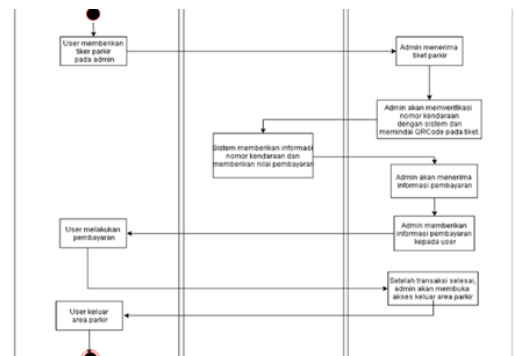


Fig. 8.  Business process proposed from manual parking entry process.
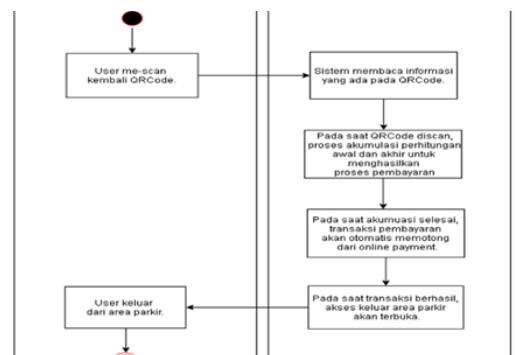


Fig. 9.  Business process proposed from manual parking exit process.

In general, the differences between current and proposed business processes based on Fig. 6 to Fig. 9 above are:

*1) Manual parking business processes:*

*a) Ticket Issuance*: In manual parking processes, when a vehicle arrives at the parking lot, a physical parking ticket is issued.

*b) Finding a Parking Spot*: The driver must manually find an available parking spot within the parking facility, which can sometimes be a time-consuming process, especially in crowded parking areas.

*c) Payment*: When leaving the parking area, the driver approaches a payment booth where they must provide the physical parking ticket and make the payment in cash or by card.

*d) Ticket Validation*: The parking ticket is manually validated by an attendant, and the gate is opened to allow the vehicle to exit the parking area.

*e)* Manual parking processes can face challenges such as ticket paper shortages, malfunctioning ticket machines, and extended waiting times, resulting in a less efficient and user-friendly experience.

*2)* Application of REST API in Ordering Tickets Online Using a Mobile Device QR Code:

*a) Ticket Ordering via Mobile App*: With the application of the REST API, users can order parking tickets online through a mobile app.

*b) QR Code Generation*: Upon ordering a parking ticket, a QR code is generated, typically displayed on the user's mobile device. This QR code serves as a digital ticket for entry and exit.

*c) Efficient Entry*: To enter the parking area, users simply need to display the QR code on their mobile device, which is then scanned by a QR code reader at the entrance gate.

*d) Online Payment*: Payment for parking can also be made online through the mobile app, reducing the need for cash payments and further expediting the process.

*e) QR Code Validation*: At the exit gate, the QR code is scanned again for validation, and the gate is opened for the user to exit.

*f)* Implementing REST API and QR Code technology offers several advantages, including faster entry and exit, reduced queues, reduced reliance on paper, and improved user convenience.

*B. Gap Analysis*

Below is a GAP Analysis table that describes the current and expected business processes. GAP analysis can be seen in Table I below:

TABLE I.     GAP ANALYSIS

| No | Business Process | Currently | Expected |
|----|------------------|-----------|----------|
| 1 | Parking Process | Manual parking process, to do parking, the user must be in the parking lot to press the ticket button and then park. | Automatic process where the previous parking process can make a booking to get a parking ticket. |
| 2 | Parking Ticket | Parking tickets currently still use paper a lot. | The expected parking ticket at this time is in addition to reducing paper in the form of a QR Code. |

In summary, manual parking business processes involve physical ticket issuance, manual search for parking spots, and payment at the booth, while the application of REST API with QR Codes allows for a more streamlined and efficient online ticket ordering process using mobile devices, reducing the reliance on physical tickets and facilitating quicker entry and exit from the parking facility.

### C. Functional Modelling Analysis

This functional modeling analysis will use the Unified Modeling Language (UML) as follows:

*1) Use case diagram*: Use Case Diagrams are used to find out what functions are in an information system and who has the right to use those functions [11]. Use Case Diagram can be seen in Fig. 10.
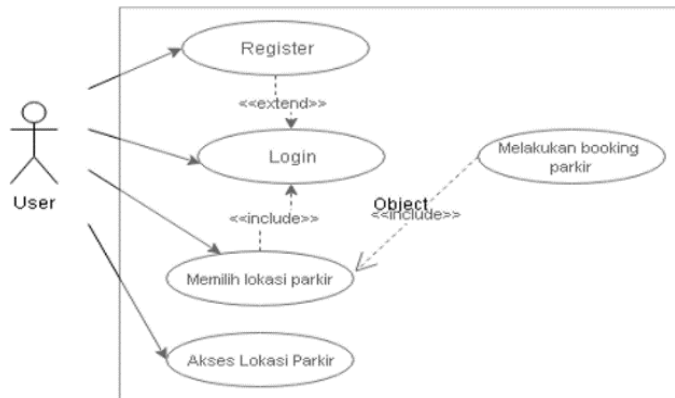


Fig. 10. Use case diagram.

*2) Class diagram*: The use of this class diagram will describe the structure in terms of defining the classes that will be created to build the system. Classes have what are called attributes and methods or operations [11]. Class Diagram can be seen in Fig. 11.
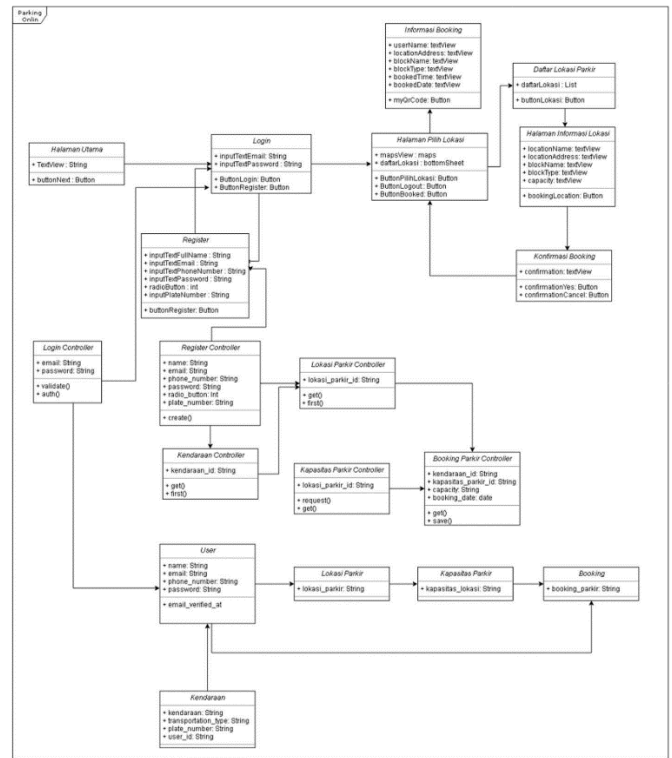


Fig. 11. Class diagram.

### D. Menu Structure Design

The design of this menu structure is a tool that is expected to make it easier for users to get to know this system better. The design of the menu structure of this system can be seen in Fig. 12.
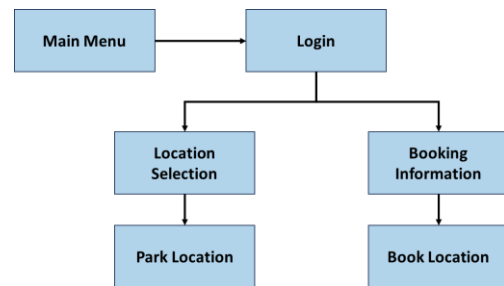


Fig. 12. Menu structure design.

### E. Interface Implementation

Implementation of the interface of this system can be seen from the description of the following points:

*1) Maps page*: Maps page that is displayed when the application is accessed, and the user has logged in. The display of this map page can be seen in Fig. 13.
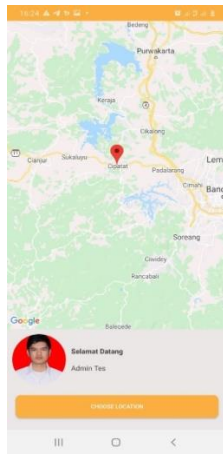
Fig. 13.  Menu structure design.

*2) Choose a parking location page*: The parking location page is the page that is displayed when the user presses the "choose location" button to select a location around them. The view of the page for choosing a parking location can be seen in the following Fig. 14.
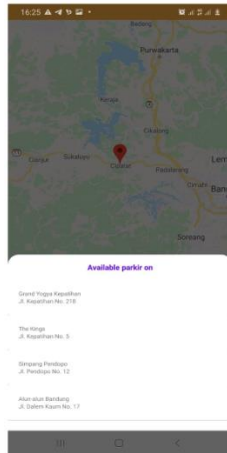


Fig. 14.  Page view select parking location.

*3) Parking information page*: The parking information page is the page after we select a location for parking which is displayed when the application is accessed. The display of this main page can be seen in Fig. 15.



Fig. 15.  Parking information page display.

*4) Booking confirmation page*: The booking confirmation page is a confirmation page that is displayed when the user has pressed the booking location button. The display of this booking confirmation page can be seen in Fig. 16.
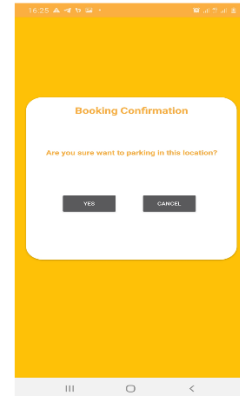


Fig. 16.  Booking confirmation page preview.

*5) QR code booking information page*: The QR Code booking information page is the page after making a booking and the QR Code will be displayed when the user presses the QR Code button. The display of this QR code booking information can be seen in Fig. 17.
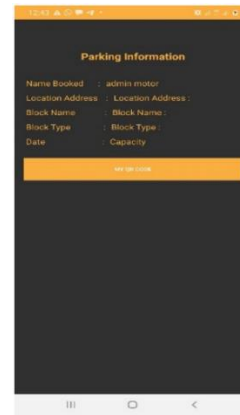


Fig. 17.  Booking information page preview.

*6) QR code page*: The QR Code Page is intended to get parking access as a substitute for parking tickets. The display of this main page can be seen in Fig. 18.



Fig. 18.  QR code page preivew.

*7) QR code page*: QR Code Scan Result is the result when the QR Code is scanned to get parking access. The display of these results can be seen in Fig. 19.



Fig. 19. QR code scan result.

When discussing API transfer for QR-Code reading mode and measuring delay (response time in milliseconds), keep in mind that this delay can be influenced by various factors, including the quality of the hardware and software used, environmental conditions, and the quality of the QR code itself. Below is Table II that includes several situations that may affect QR-Code reading delay:

TABLE II.  FACTORS THAT HINDER THE TRANSFER OF QR CODE DATA USING THE REST API

| No | Factor / Issue | Estimated Delay (ms) | Description |
|----|----------------|----------------------|-------------|
| 1 | Environmental Conditions | 10-100 | Low light, glare, or shadows can slow down QR code reading. |
| 2 | QR Code Quality | 5-50 | Damaged or non-standard QR codes may require extra time for decryption. |
| 3 | Camera Hardware | 20-100 | The quality of the camera on mobile devices or QR code readers can affect response time. |
| 4 | Software Application | 10-50 | The performance of QR code reader software may vary based on the implementation and updates. |
| 5 | Processor Speed | 5-20 | Faster mobile device or QR code reader processors will read QR codes more quickly. |
| 6 | Network Overhead | 20-100 | If QR codes need to be fetched from a server over a network, network overhead can impact delay. |

The values in this table are general estimates and may vary depending on the actual circumstances. Some cases may experience higher or lower delays depending on the combination of these factors. Additionally, more advanced hardware and software may experience lower delays. Implementing REST APIs for online ticket booking using QR codes on mobile devices can have various advantages and disadvantages. Here are some of them:

*1) Excess*:

*a) Ease of Access and Use*: The REST API allows users to easily access the ticket booking system using their mobile devices. This provides convenience for users in ordering public transportation tickets.

*b) Scalability*: The REST API allows the system to easily scale to changing demands. It can handle traffic spikes that occur during peak hours or during special events.

*c) Interoperability*: REST APIs typically use common data formats such as JSON, which can be easily understood by various devices and platforms. This allows various third-party applications to integrate with the ticket booking system.

*d) Security*: REST APIs can be configured to implement security measures such as authentication, authorization, and data encryption to protect user information and payment transactions.

*e) R codes*: Using QR codes simplifies the check-in process on public transportation. Users simply display their QR code on their phone screen, and officers can quickly scan it to validate the ticket.

*2) Weakness*:

*a) Dependency on Internet Connection*: REST API requires a stable internet connection. If users are in an area with a weak signal or no internet connection, they may not be able to book tickets or display their QR code.

*b) Technical Errors*: In the event of technical glitches or server failure, users may experience difficulty booking tickets or using QR codes. This can disrupt the user experience.

*c) Data Security*: Although REST APIs can be regulated with security measures, the risk of data leakage remains. Users' personal data and payment information must be guarded very strictly.

*d) Development Cost*: Developing and maintaining a robust and reliable REST API can require a large investment in terms of human and financial resources.

*e) Need for Continuous Maintenance*: APIs need to be maintained and updated regularly to maintain their reliability. This requires additional effort and costs.

*f) Regulatory Compliance*: Online ticket booking systems must comply with various regulations, including data privacy and financial regulations, which can add complexity and operational costs.

Implementing REST APIs in online ticket ordering using QR codes on mobile devices can provide many benefits, but also has several challenges that must be overcome to achieve success in managing public transportation in a smart city ecosystem.

## V. CONCLUSION

The conclusions obtained from the activities that have been carried out include the existence of an online process that can facilitate the process of getting information about the place without having to look directly at the parking lot, making it easier for users to book a parking space. This activity can also anticipate problems in the vehicle parking process such as running out of parking tickets, jammed ticket machines that create long queues. With QR Code media as a substitute for parking tickets, it will save paper usage which is usually always thrown away after use, so this QR Code is one of the media used can replace paper tickets. Implementing the REST API in online ticket ordering using a QR code on a mobile

device is one of the best solutions for managing public transportation in the smart city ecosystem.

REFERENCES

[1] Parmar, J., Das, P., & Dave, S. M. (2020). Study on demand and characteristics of parking system in urban areas: A review. Journal of Traffic and Transportation Engineering (English Edition), 7(1), 111-124.

[2] Calderdale Council. (2023). Mitigating Circumstances For Appealing Against A Ticket, https://new.calderdale.gov.uk/parking/challenging-parking-ticket/mitigating-circumstances, Accessed October 21, 2023

[3] A. F. Harismawan, A. P. Kharisma, and T. Afrianto, "Analisis Perbandingan Performa Web Service Menggunakan Bahasa Pemrograman Python, PHP, dan Perl pada Client Berbasis Android," Jurnal Pengembanagan Teknologi Informasi dan Ilmu Komputer, vol. 2, no. 1, 2018.

[4] D. L. Puspa, I. Uce, and H. S. Yulius, "Permodelan Proses Bisnis menggunakan Activity Diagram UML dan BPMN," Universitas Kristen Petra, 2009.

[5] A. Mayasari, "A. Sistem Reservation dan Ticketing PT. Sriwijaya Air Distrik Solo," Universitas Sebelas Maret Surakarta, 2011.

[6] S. Hanief, and D. Pramana, "Pengembangan Bisnis Pariwisata Dengan Media Sistem Informasi," 2018.

[7] Herlinah, and K. H. Musliadi, "Pemrograman Aplikasi Android dengan Android Studio, Photoshop dan Audition, No. 1, pp. 2-5, 2019.

[8] Denso Wave Corporation, "QR Code Essentials," 2011.

[9] A. S. Rosa, and M. Shalahuddin, "Rekayasa Perangkat Lunak Dan Berorientasi Objek," 2016.

[10] Sitorus, L., Situmorang, J. V. M., Limbong, T., Matondang, Z. A., & Rikki, A. (2023, July). Development of quality assurance information systems at the faculty of Computer Sciences, Santo Thomas Catholic University with rapid application development (RAD) model. In AIP Conference Proceedings (Vol. 2798, No. 1). AIP Publishing.

[11] G. B. Shelly, T. J. Cashman, and H. J. Rosenblatt, "System Analysis and Design," 7th ed, Course Technology, 2008.

[12] I. Abubakar, "Pedoman Perencanaan Dan Pengoperasian Fasilitas Parkir," 1998.

[13] M. Masse, "REST API Design Rulebook," 2011.

[14] V. Brossier, "Developing Android Applications with Adobe Air," 2011.

# Design of Distributed Cooperative Control for Multi-Missile System to Track Maneuvering Targets

Belkacem Kada[*], Khalid A. Juhany, Ibraheem Al-Qadi, Mostefa Bourchak
Aerospace Engineering Department, King Abdulaziz University, Jeddah, KSA

*Abstract*—The current paper provides unique smooth control methods for constructing resilient nonlinear autopilot systems and cooperative control protocols for single and multi-missile systems. To develop the single autopilots, a high-order framework based on asymptotic output stability principles and local relative degree for nonlinear affine systems is first applied. Then, using asymptotic exponential functions and graph theory, free-chattering distributed protocols are constructed to allow multi-missile systems to track and intercept high-risk targets. The Lyapunov approach is used to derive the essential requirements for smooth asymptotic consensus. The proposed method minimizes computing load while enhancing accuracy. The simulation results indicate the efficacy of the recommended strategies.

*Keywords—Multi-missile cooperative control; missile autopilot; smooth control; high-order sliding mode; target tracking*

## I. INTRODUCTION

To adhere to the intended trajectory, a modern tactical missile (TM) autopilot system must be able to stabilize the rotational dynamics of the missile and accurately monitor the sequence of acceleration commands issued by the navigation and guidance system. However, constructing a missile's autopilot is a difficult challenge due to the unpredictability in aerodynamic derivatives.

Early missile autopilots were built using traditional methods, notably linearized dynamic models within a gain scheduling control approach. Using linear design methodologies within a gain scheduling framework, on the other hand, frequently resulted in suboptimal control where no stability or performance certificate could be given by the closed-loop system constituted of the nonlinear plant and planned controller. Several nonlinear control strategies have been developed to reduce the needed gain scheduling.

A nonlinear pitch-axis autopilot involving scheduling linear $H_\infty$ control design under constant operating conditions and bounded scheduling variables was first discussed in [1]. In the work presented in [2], gain-scheduling and gap metric techniques were used to design a robust missile pitch-axis autopilot for an air-to-air missile. The connection between the loop-shaping theory and the gap metric technique was used to compute the operating points, and proportional-integral/proportional-type controllers were designed. The problem of the missile's autopilot design in the presence of hidden coupling terms was tackled in [3] using gain-scheduling control. The study introduced a self-scheduling method for preserving the local properties of the nonlinear gain-scheduled controller, which allows for consideration of

the hidden coupling terms during the design process. The nonlinear pitch dynamics of a tail-controlled, extremely agile missile were addressed in [4] by designing a gain-scheduled 4-loop autopilot. The requirements for an autopilot's design were methodically converted into hard and soft tuning objectives, and the resulting multi-model/multi-objective issue was then addressed with the help of a nonsmoothed optimization process.

Many design schemes have recently been developed to provide stringent performance requirements and ensure robustness across different flight conditions. The Linear Parameter Varying (LPV) approach was recently used conjointly with linear fractional transformation (LFT) in [5] to design specified structure autopilots that ensure robustness to a large class of uncertainty. The proposed LPV/LFT algorithm could handle slope-restricted nonlinearities and rate-bounded time-varying parameters using a nonsmooth optimization technique and using polytopic LPV weights within the four-block loop-shaping H∞ loop shaping theory, the authors, in [6], designed an output feedback controller to provide a missile longitudinal autopilot with robust H∞ performance. To accommodate the seeker field-of-view constraint while maintaining the system's resilience, an integrated missile guidance and control method was developed in [7] by appending the integral barrier Lyapunov function to dynamic surface control. As uncertain disturbances of the system, the authors treated target maneuvering and unmodeled disturbances with the influence of the disturbance rejection rate error. They employed an extended state observer for real-time estimates.

The study in [8] offered a sliding mode control (SMC) architecture for precision missile operation inside a nonlinear finite-time control framework, as opposed to the asymptotically convergent control framework. The study's most significant contribution was analysing the influence of boundary layer thickness on missile system reactions, with the assumption that reducing boundary layer thickness will improve the control performance of the SMC autopilot system.

On the other hand, as the multilayered missile defense system has been refined and target maneuverability has increased, the challenge of penetrating a target with a single traditional missile has increased in recent years. In such a case, cooperative guiding is recommended as a viable countermeasure to boost missile penetrability. To improve the lethality of multiple missiles, cooperative guiding laws must also meet time and space restrictions, in addition to attaining a minimal or even zero miss distance. Many recent studies [9-

14] have concentrated on the topic of distributed cooperative guidance of multi-missile systems.

In this study, we first suggested a new high-order SMC-based technique for developing the guidance law, which serves as the foundation for estimating the ideal flying AOA and normal acceleration trajectories. The goal of this technique is to look at the use of finite-time control for the longitudinal dynamics of a tactical missile, with the needed information acting as the control command. We propose a smooth control-based design of distributed consensus protocols for multi-missile system guiding in the second half. Free-chattering distributed protocols are constructed using asymptotic exponential functions and graph theory. The essential criteria for smooth asymptotic tracking are derived using the Lyapunov method.

## II. MISSILE DYNAMICS AND CONTROL OBJECTIVES

A TC system is a type of guided missile designed for use in combat situations with a relatively limited range, typically within the theatre of operations or on the battlefield. These missiles are designed to execute pinpoint attacks against hostile installations, vehicles, aircraft, and ships. Fig. 1 shows a typical TM model.
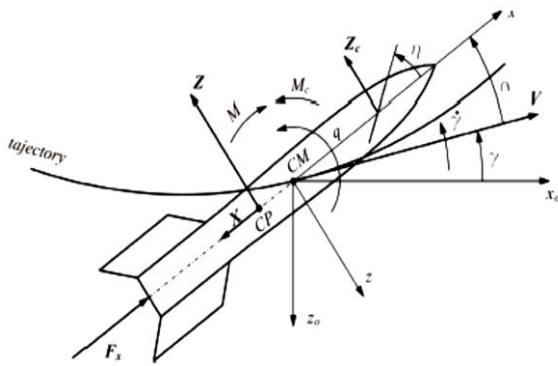


Fig. 1. Missile pitch-axis motion.

The Reichert's missile model [1], a hypothetical fin-controlled pitch-axis missile that serves as a standard in studies of nonlinear controller design for supersonic and hypersonic vehicles, is employed as the basis for the present study.

The nonlinear dynamic model presented below governs the missile's motion in the planar space.

$$\dot{M} = K_z M^2 \left[ C_{D_0} - C_z(\alpha, M) \sin\alpha \right] - \frac{g}{v_s} \sin\gamma \quad (1)$$

$$\dot{\alpha} = K_z M C_z(\alpha, M) co \frac{g}{v_s M} \cos\gamma + q \quad (2)$$

$$\dot{q} = K_m M^2 C_m(\alpha, M) \quad (3)$$

$$\dot{\gamma} = -K_z M C_z(\alpha, M) \cos\alpha - \frac{g}{v_s M} \cos\gamma \quad (4)$$

where:

- $M$ is the Mach number.

- $\alpha$ is the angle-of-attack (AOA) (rad).

- $q$ is the pitch rate (rad/s).

- $\gamma$ is the flight path angle (rad).

The nonlinear coefficients $C_z$ and $C_m$ characterize the missile aerodynamics model's and are given as time-varying parameters.

$$C_z = a_z \alpha^3 + b_z |\alpha| \alpha + c_z \left( 2 - \frac{M}{3} \right) \alpha + d_z \delta \quad (5)$$

$$C_m = a_m \alpha^3 + b_m |\alpha| \alpha + c_m \left( -7 + \frac{8M}{3} \right) + e_m q + d_m \delta \quad (6)$$

Considering the above four flight parameters as system's states and the fin deflection (6) as control input, model (1)-(4) becomes.

$$\dot{x} = f(x) + g(x)u$$
$$y = h(x) \quad (7)$$

with

$$x = [M \ \alpha \ q \ \gamma]^T \quad (8)$$

$$h = \eta(M, \alpha) \quad (9)$$

$$u = \delta \quad (10)$$

where the missile's normal acceleration $\eta$ is given by

$$\eta = K_z M^2 v_s C_z(\alpha, M) \quad (11)$$

and $f(x) \in \mathbb{R}^4$, $g(x) \in \mathbb{R}^4$, and $h(x) = \eta \in \mathbb{R}$ are uncertain bounded functions. $f(x), g(x)$ and $h(x)$ are uncertain due the uncertainty of the aerodynamics coefficients given in (5) and (6). The expended form of the model (7) is given below:

$$f_1(x) = -\frac{g}{v_s} \sin x_3 - K_z x_1^2 \left[ C_{D_0} - \left( a_z x_2^3 + b_z |x_2| x_2 + c_z \left( 2 - \frac{x_1}{3} \right) x_2 \right) \right] \sin x_2 \quad (12)$$

$$f_2(x) = +\frac{g}{v_s x_1} \cos x_3 + x_4 K_z x_1 \left[ a_z x_2^3 + b_z |x_2| x_2 + c_z \left( 2 - \frac{x_1}{3} \right) x_2 \right] \cos x_2 \quad (13)$$

$$f_3(x) = -K_z x_1 \left[ a_z x_2^3 + b_z |x_2| x_2 - \frac{g}{v_s x_1} \cos x_3 + \left( 2 - \frac{x_1}{3} \right) x_2 \right] \cos x_2 \quad (14)$$

$$f_4(x) = K_m x_1^2 \left[ a_m x_2^3 + b_m |x_2| x_2 \left( -7 - \frac{8x_1}{3} \right) x_2 \right] \quad (15)$$

$$g(x) = [0 \ 0 \ 0 \ K_m x_1^2 d_m]^T \quad (16)$$

$$h(x) = K_z x_1 \left[ a_z x_2^3 + b_z |x_2| x_2 + c_z \left( 2 - \frac{x_1}{3} \right) x_2 \right]. \quad (17)$$

Achieving the intended mission in a short time while accounting for external disturbances and model uncertainties is the goal of the present control design. The performance objectives for the closed-loop system encompass the achievement of finite-time closed-loop convergence, fast response to substantial manoeuvres, the system's ability to withstand and adapt to plant uncertainties and disturbances.

## III. HIGH-ORDER SLIDING MODE CONTROL TO MISSILE AUTOPILOT DESIGN

### A. Lie Derivatives for Nonlinear Affine Control

Consider a vector field $f(x) \in \mathbb{R}^n$ defined on open operating domain $D \in \mathbb{R}^n$ and a smooth map $m \in \mathbb{R}^p$. For any $x \in m$, The Lie derivatives, along the trajectory $f(x)$, for the map $m$ are given as follows:

$$L_f m(x) = \frac{d}{dt} m\big(\phi_i^f(x)\big)\Big|_{t=0} \tag{18}$$

where, $\phi_i^f(x)$ denotes the flow vector of $f(x)$ at time t. Using the chain rule, one can write

$$L_f m(x) = m^{(1)}(x) f(x) \tag{19}$$

with $m^{(1)} = \partial m / \partial x$ being the Jacobian matrix of $m$. Therefore, the $r$-derivative of $m$ is given as

$$\begin{cases} L_f^r m(x) = m^{(r-1)}(x) f(x) \\ L_f^0 m(x) = m(x) \end{cases} \tag{20}$$

According to the Lie derivatives properties, for a further vector $g$, expression (20) becomes

$$L_g L_f m(x) = \frac{\partial L_f m(x)}{\partial x} g(x) \tag{21}$$

### B. Sliding Mode Control Design

Consider the following tracking error to be the actual output of a multi-output system with $\in \mathbb{R}^p$.

$$e(y) = y - y_d \tag{22}$$

where, $y_d$ denotes the desired values of $y$. The system equilibrium point is located on the manifold $e_i^{-1}(0)) = \{x| e_i(x) = 0\}$).

Definition 1. The derivative degree $r$ in equation (20) extends, for the case (22), to the vector $r = \begin{bmatrix} r_1 & r_2 & \dots & r_p \end{bmatrix}^T$ for which expression (20) and (21), for a given initial condition $x_0$, become

$$\begin{cases} L_g L_f^k e_i(x) = 0 \\ L_g L_f^{r_i-1} e_i(x_0) \neq 0 \end{cases} \quad 0 \leq k \leq r_i - 2, 1 \leq i \leq p \tag{23}$$

Following is the calculation of the derivatives in (23) that appear in sequence.

$$\begin{bmatrix} L_f \\ L_f^k \\ L_g \end{bmatrix} e_i(x) = \begin{bmatrix} \sum_{i=1}^n \frac{\partial e_i}{\partial x_i} f_i(x) \\ L_f\left(L_f^{k-1} e_i(x)\right) \\ \sum_{i=1}^n \frac{\partial e_i}{\partial x_i} g_i(x) \end{bmatrix} \tag{24}$$

Lemma 1 [xx]. If and only if the following holds for any subset of the domain of the output $e_i$, then the relative degree $r_i$ is well-defined there.

$$L_g L_f^{r_i-1} e_i(x_0) = \tau \tag{25}$$

where $\tau$ is a constant.

Lemma 2 [xx]. For each $e_i$ with $r_i > 1$, a stable motion towards zero can be obtained for the sequence $\left(e_i, e_i^{(1)}, e_i^{(2)}, \dots, e_i^{(r_i-1)}\right)$ by designing the following sliding manifold that satisfies $\sigma_i^{-1}(0) = \{x| \sigma_i(x) = 0\}$

$$\begin{aligned} \sigma_i(x) = {}& L_f^{r_i-1} e_i(x) + \lambda_{r_i-2} L_f^{r_i-2} e_i(x) + \cdots \\ & + \lambda_1 L_f e_i(x) + \lambda_0 e_i(x). \end{aligned} \tag{26}$$

with $\lambda_j > 0$ $(j = r_i - 2, \dots, 0)$ define design parameters.

Lemma 3 [xx]: The following equation has a single local solution, denoted by the affine control u(x)

$$\begin{aligned} \big[L_f \sigma_i(x)\big] = \big[ & L_f^{r_i} e_i(x) + \\ & \lambda_{r_i-2} L_f^{r_i-1} e_i(x) + \cdots + \lambda_0 L_f e_i(x)\big] = 0 \end{aligned} \tag{27}$$

Remark 1: If a relative degree $r_i$ is defined for each output $y_i$ with respect to a control input $u$, then the smallest relative degree $\rho > 1$ is considered as the relative degree of the whole system (i.e., $\rho = \min(r_i)$, and $\rho > 1$).

Remark 2: A well-defined relative degree guarantees the applicability of such a controller over the working range, while the smallest relative degree simplifies the design task and gives a practical controller. The outer-loop sliding mode controller's primary characteristic is shown in the following block diagram.

### C. AOA Autopilot

With $e_2 = \alpha - \alpha_d = x_2 - x_{2,d}$ and $\frac{\partial \alpha_d}{\partial x} = \frac{\partial x_{2,d}}{\partial x}$, the Lie derivatives (24) are computed as follows

$$L_g \begin{bmatrix} e_1(x) \\ e_2(x) \\ e_3(x) \end{bmatrix} = L_g L_f \begin{bmatrix} e_1(x) \\ 0 \\ e_3(x) \end{bmatrix} = 0_{3x1} \tag{28}$$

$$L_g L_f^2 \begin{bmatrix} e_1(x) \\ e_2(x) \\ e_3(x) \end{bmatrix} = g(x) \begin{bmatrix} \frac{\partial f_1(x)}{\partial x_2} \\ 1 \\ \frac{\partial f_3(x)}{\partial x_2} \end{bmatrix} \tag{29}$$

Considering property (25), the AOA's relative degree is $r_\alpha = 2$. This proves that there exists a well-defined output-input assignment $\forall x \in O(x_0)$. According to the value of $r_\alpha$, the sliding manifold (26) becomes

$$\sigma(x) = \frac{\partial e_2}{\partial x} f + \lambda e_2 = \frac{\partial x_2}{\partial x} f + \lambda(x_2 - x_{2,d}) \tag{30}$$

Applying Lemma 3, the fin deflection that ensure $\sigma(x) = 0$ is derived as follows:

$$\delta(x) = \left(\frac{1}{1 + g(x)}\right) - \left(u(x) + K sat\left(\sigma(x)/\varepsilon\right)\right) \tag{31}$$

where the saturation function is implemented using a boundary layer $\varepsilon$ s

$$sat(^\sigma/_\varepsilon) = \begin{cases} ^\sigma/_\varepsilon & if\ |^\sigma/_\varepsilon| \leq 1 \\ sgn(^\sigma/_\varepsilon) & if\ |^\sigma/_\varepsilon| > 1 \end{cases} \quad (32)$$

In this design, the gain $K$ is provided to correct model uncertainties, unmodeled dynamics, and measurement noises, the coefficient sets the bandwidth of the error dynamics, and the layer $\varepsilon$ is introduced to dampen the babbling.

### D. Normal Acceleration Autopilot

The rate of the missile's acceleration is one of the primary variables managed by an autopilot system. Commonly symbolized by the letter "g" normal acceleration quantifies the gravitational pull experienced by the airframe in flight. Using normal acceleration autopilot to deflect the fins allows controlling a measured variable, which avoids the use of an estimator for $\alpha$. To do so, we compute the inverse transformation of Eq. (11).

$$\alpha(\eta, M) = K_z M^2 \begin{bmatrix} \dfrac{2b_z^2 - a_z c_z(2 - M/3)}{K_z^3 M^2 c_z^5 (2 - M/3)^5} \eta^3 \\ -\dfrac{b_z}{K_z^2 c_z^3 (2 - M/3)^3} |\eta|\eta \\ +\dfrac{1}{K_z M^2 c_z (2 - M/3)} \eta \end{bmatrix} \quad (33)$$

From (33), the time derivative of $\eta$ is given as follows

$$\dot{\eta} = \left(\frac{\partial \alpha}{\partial \eta}\right)^{-1} \left[ K_z M C_z(M, \eta) + q(M, \eta) - \frac{\partial P}{\partial M} \dot{M}(M, \eta) \right] \quad (34)$$

The sliding manifold and its corresponding control input are given as follows

$$\begin{cases} \sigma(x) = \dfrac{\partial \eta}{\partial x} f + \lambda(\eta - \eta_d) \\ \dfrac{\partial}{\partial \gamma} \dfrac{\partial \dot{\eta}}{\partial x} f(x) + \lambda \dfrac{\partial \dot{\eta}}{\partial \gamma} = 0 \end{cases} \quad (35)$$

## IV. DISTRIBUTED MISSILE AUTOPILOT DESIGN

In the context of a fixed topology, we present, in this section, the design of distributed consensus protocols $u_i$ to allow a multi-missile system, composed of $m$ agents, to track an AOA or normal acceleration commands to ensure a successful interception of high-risk targets. To do so, a consensus tracking error is defined as follows:

$$e_i = \sum_{j=0}^{n} a_{ij}(x_i(t) - x_j(t)) \quad (36)$$

where, $a_{ij}$ denote the elements of the the adjacent matrix $\mathcal{A}$ and $x_i \in \mathbb{R}^n$ denotes the individual missiles state vector.

Definition 2: Based on the consensus (36), we define, for each agent '$i$' (e.g., individual missile) the following inequality.

$$\|\psi_i(e_i)\|_2 \leq \|\psi_i(e_i)\|_1 \leq N\|\psi_i(e_i)\|_\infty \leq N\kappa \quad (37)$$

with $N = nm$ and $\kappa \in \mathbb{R}^+$

Definition 3: According to the communication graph $\mathcal{G}$ of the multi-missile system, we define a matrix $M$ such that $M = \mathcal{L} + \mathcal{D}_0$ with $\mathcal{L} = \mathcal{D} - \mathcal{A}$ being the Laplacian matrix associated with $\mathcal{G}$, $\mathcal{D}_0 = diag(a_{i0})$, and $\mathcal{D} = diag(d_i = \sum_{j=1}^{n} a_{ij})$.

Definition 4: The missiles' dynamics are bounded

$$\|f_i(x_i)\|_2 \leq \rho\|x_i\|_2, \|f_i(x) - f_i(y)\|_2 \leq \gamma\|x - y\|_2 \quad (38)$$

with $\rho, \gamma \in \mathbb{R}^+$.

Theorem 1: Based on the properties of the matrix $M$, If the fixed-time undirected graph $\mathcal{G}$ is connected and at least one $a_{i0} > 0$, the leader-follower consensus (36) is asymptotically guaranteed by the following distributed consensus control.

$$u_i = -k_1 e_i - k_2 \psi_i(e_i) \quad (39)$$

*where,* $k_1$, $k_2$ are the consensus gains satisfying.

$$\begin{cases} k_1 \geq \rho \dfrac{\lambda_{\max}(\boldsymbol{M})}{\lambda_{\min}^2(\boldsymbol{M})} \\ k_2 \geq \dfrac{\sqrt{\tilde{\boldsymbol{x}}_0^T(\boldsymbol{M} \otimes \boldsymbol{I}_N)\tilde{\boldsymbol{x}}_0}\sqrt{\lambda_{\max}(\boldsymbol{M})}}{t_s \lambda_{\min}(\boldsymbol{M})N\kappa}(1 + d_0) \\ t_s = \dfrac{\sqrt{\tilde{\boldsymbol{x}}_0^T(\boldsymbol{M} \otimes \boldsymbol{I}_N)\tilde{\boldsymbol{x}}_0}\sqrt{\lambda_{\max}(\boldsymbol{M})}}{k_2 \lambda_{\min}(\boldsymbol{M})N\kappa} \end{cases}$$

$$(40)$$

with $\lambda_{min}(M) > 0, \kappa > 0$, and $t_s$ is the settling time.

Proof:

For each agent $'i'$, let us consider a tracking error denoted as $\tilde{x}_i = x_i - x_0$. By employing the distributed consensus protocol (38), the multi-agent closed-loop system is written as follows:

$$\dot{\tilde{x}}_i = f_i(x_i) - f_0(x_0) - k_1 \sum_{j=1}^{n} a_{ij}(\tilde{x}_i - \tilde{x}_j) - k_2\psi_i(\tilde{e}_i) \quad (41)$$

where, $\tilde{e}_i = \sum_{j=0}^{n} a_{ij}(\tilde{x}_i - \tilde{x}_j)$. For the muti-agent system, we write

$$\dot{\tilde{x}} = F(\tilde{x}, \tilde{x}_0) - k_1(M \otimes I_N)\tilde{x} - k_2\Psi(\tilde{e}) \quad (42)$$

with

$$\tilde{x} = [\tilde{x}_1^T, \dots, \tilde{x}_n^T]^T,$$
$$F(\tilde{x}, x_0) = \left[(f_1(x_1) - f_0(x_0))^T, \dots (f_n(x_n) - f_0(x_0))^T\right]^T,$$
$$\Psi(\tilde{e}) = [\psi_1^T(\tilde{e}_1), \dots, \psi_n^T(\tilde{e}_n)]^T$$

where, $f_0(x_0)$ denotes the vector field of the leader dynamics and $x_0$ denotes its state vector. To demonstrate the effectiveness of the proposed control algorithm, we consider the following Lyapunov function candidate.

$$V = \frac{1}{2}\tilde{x}^T(M \otimes I_N)\tilde{x} \quad (43)$$

for which,

$$\dot{V} = \tilde{x}^T (M \otimes I_N)[F(\tilde{x}, x_0) - k_1 (M \otimes I_N)\tilde{x} - k_2 \Psi(\tilde{e})] \quad (44)$$

with $\lambda_{min}(M) > 0$, one can get

$$\begin{cases} \tilde{x}^T (M \otimes I_N)F((\tilde{x}, x_0)) = F^T((\tilde{x}, x_0))(M \otimes I_N)\tilde{x} \\ \qquad\qquad \le \rho \lambda_{max}(M) \|\tilde{x}\|_2^2 \\ \tilde{x}^T (M \otimes I_N)^2 \tilde{x} \, \lambda_{min}^2 \ (M) \|\tilde{x}\|_2^2 \end{cases} \quad (45)$$

It results,

$$\dot{V} \le -k_1 \lambda_{min}^2(M) \|\tilde{x}\|_2^2 - \rho \lambda_{max}(M)\|\tilde{x}\|_2^2 \\ + \lambda_{min}(M)\|\Psi(\tilde{e})\|_2 \|\tilde{x}\|_2 \quad (46)$$

Suppose that there exist $\kappa \in \mathbb{R}^+$ for which

$$\|\psi_i(e_i)\|_2 \le \|\psi_i(e_i)\|_1 \le N\|\psi_i(e_i)\|_\infty \le N\kappa \quad (47)$$

It results that condition (46) is achieved if and only if

$$k_1 \lambda_{min}^2(\boldsymbol{M})\|\tilde{\boldsymbol{x}}\|_2^2 - \rho\lambda_{max}(\boldsymbol{M})\|\tilde{\boldsymbol{x}}\|_2^2 = \left(k_1 - \rho\frac{\lambda_{max}(\boldsymbol{M})}{\lambda_{min}^2(\boldsymbol{M})}\right)\lambda_{min}^2(\boldsymbol{M})\|\tilde{\boldsymbol{x}}\|_2^2 \ge 0$$

$$k_2 \lambda_{min}(\boldsymbol{M})\|\boldsymbol{\Psi}(\tilde{\boldsymbol{e}})\|_2\|\tilde{\boldsymbol{x}}\|_2 - d_0 = \frac{k_2 \lambda_{min}(\boldsymbol{M})\sqrt{2V}}{\sqrt{\lambda_{max}(\boldsymbol{M})}}\|\boldsymbol{\Psi}(\tilde{\boldsymbol{e}})\|_2 - d_0 \ge 0 \quad (48)$$

where, $d_0$ is the maximum value of an eventual disturbance ($d_0 = 0$ for undisturbed system). With $k_1 \ge \rho\frac{\lambda_{\max}(M)}{\lambda_{min}^2(M)}$, $\dot{V}$ will satisfy

$$\dot{V} \le -\frac{k_2 \lambda(M)\sqrt{2V}_{min}}{\sqrt{\lambda(M)}_{max}\|\Psi(\tilde{e})\|_1} \le -\frac{k_2 \lambda(M)\sqrt{2V}_{min}}{\sqrt{\lambda(M)}_{max}N\|\Psi(\tilde{e})\|_\infty} \quad (49)$$

It follows,

$$\begin{cases} \sqrt{V} \le \sqrt{V_0} - \dfrac{k_2}{\sqrt{2}}\dfrac{\lambda(M)\|\Psi(\tilde{e})\|_\infty{}_{min}}{\sqrt{\lambda(M)}_{max}t} \\[2mm] t_s = \dfrac{\sqrt{\tilde{x}_0^T(M\otimes I_N)\tilde{x}_0}\sqrt{\lambda(M)_{max}}}{k_2\lambda(M)_{min}} \\[2mm] k_1 \ge \rho\dfrac{\lambda_{max}}{\lambda_{min}^{2(M)}} \\[2mm] k_2 \ge \dfrac{\sqrt{\tilde{x}_0^T(M\otimes I_N)\tilde{x}_0}\sqrt{\lambda(M)_{max}}}{t_s\lambda(M)_{min}(1+d_0)} \end{cases} \quad (50)$$

## V. RESULTS AND DISCUSSION

*First scenario:* A quick, high-maneuver normal acceleration tracking scenario is used to assess the performance and reliability of the normal acceleration autopilot for a single missile airframe. As it can be seen in Fig. 2, the commanded acceleration and initial Mach number were chosen at their extremes. The results show that the proposed technique is effective for controlling such complex system.

*Second scenario:* In this section, first, the tracking of an AOA sequence using the state feedback-based autopilot is performed by a multi-missile composed of six agents. The AOA sequence is introduced as step commands given at different initial AOA $\alpha_0 = [-5 \quad 0 \quad 20 \quad -7.5 \quad 5 \quad -20]^T$ and $M = 3$. The communication topology is shown in Fig. 3 and the time-history of the tracking mission is shown in Fig. 4.
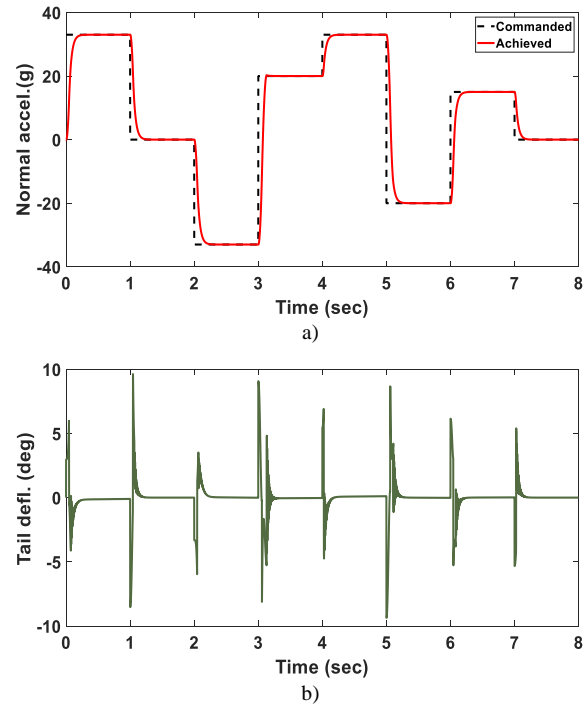


Fig. 2. Single missile response to a normal acceleration pattern: a) Normal acceleration, b) Tail deflection.
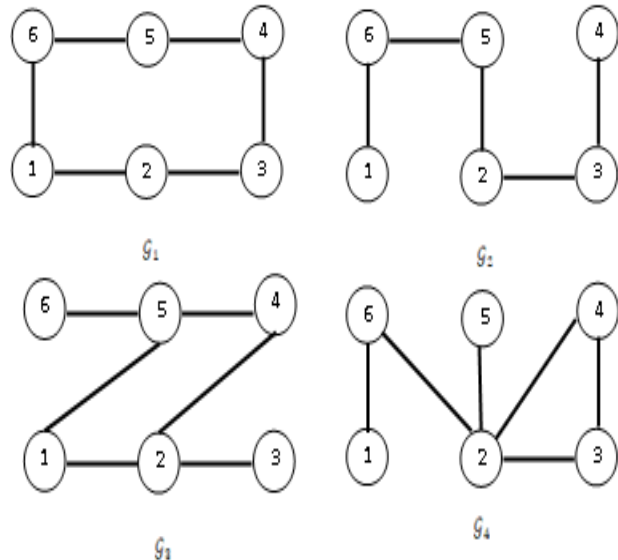


Fig. 3. Fixed-time switching topology connected interaction graph.

Fig. 4. Time history of multi-missile system response: a) AOA, b) Normal acceleration, C) Fin deflection.

## VI. CONCLUSION

In this study, we first designed two robust longitudinal autopilot topologies for a tail-controlled tactical missile. The two autopilots were created with high-order sliding mode control and a thorough nonlinear dynamic model. Second, we looked at the distributed control-based cooperative guiding problem for a multi-missile system intercepting a high-risk target. Asymptotic exponential functions and graph theory were used to create free-chattering distributed protocols. The Lyapunov technique was used to determine the necessary requirements for smooth asymptotic tracking. The simulation findings show that there is reduced computing load and more precision. Future study will focus on various features of multi-missile systems for practical implementations, such as the distinct overload and impact angle limits of each missile, communication delays, and robustness consensus.

## REFERENCES

[1] Nichols A. Robert, Reichert T, Robert, and Rugh J. (1993). Gain Scheduling for H-Infinity Controllers: A Flight Control Example. In: IEEE Transactions on Control Systems Technology. vol. 1, No. 2, pp 69-79.

[2] Theodoulis S. and Duc G., "Missile Autopilot Design: Gain-Scheduling and the Gap Metric," Journal of Guidance, Control, and Dynamics, Vol. 32, No. 3, 2009, pp. 986–996.

[3] Lhachemi H., Saussié D. and Zhu G., "Gain-Scheduling Control Design in the Presence of Hidden Coupling Terms," Journal of Guidance, Control, and Dynamics, Vol. 39, No. 8, 2016, pp. 1871–1879.

[4] heodoulis S., Proff M. and Marchand C., "Robust Design for Highly Agile Missile Autopilots," 28th Mediterranean Conference on Control and Automation, Inst. of Electrical and Electronics Engineers, New York, 2020, pp. 67–72.

[5] Alberto M. Simões and Vinícius M. G. B. Cavalcanti (2023). Missile Autopilot Design via Structured Robust Linear Parameter-Varying Synthesis, Journal of Guidance, Contrand Dynamics, vol. 46, no. 8, doi:10.2514/1.g007580.

[6] Y. M. Tavares and J. Waldmann, "H∞ Loop Shaping Using Polytopic Weights and Pole Assignment to Missile Autopilot," in *IEEE Access*, vol. 11, pp. 125-133, 2023, doi: 10.1109/ACCESS.2022.3232464.

[7] S. -Y. Lin, J. Wang and W. Wang, "Barrier Lyapunov Function Based Integrated Missile Guidance and Control Considering Phased Array Seeker Disturbance Rejection Rate," in *IEEE Access*, vol. 10, pp. 31070-31083, 2022, doi: 10.1109/ACCESS.2022.3156292.

[8] Yadong, C., Zhaoke, N., Kai, Z., Bin, L. (2023). Multi-missile Cooperative Strike on Stationary Target Based on Distributed Model Predictive Control. In: Yan, L., Duan, H., Deng, Y. (eds) Advances in Guidance, Navigation and Control. ICGNC 2022. Lecture Notes in Electrical Engineering, vol 845. Springer, Singapore. https://doi.org/10.1007/978-981-19-6613-2_261.

[9] W. Tian, Q. Yang and Q. Zhao, "Cooperative Guidance of Multi-missile over Random Communication Networks," *2022 34th Chinese Control and Decision Conference (CCDC)*, Hefei, China, 2022, pp. 5602-5607, doi: 10.1109/CCDC55256.2022.10033769.

[10] Q. Wang, P. Lu and Y. Tian, "Finite-time Simultaneous-Arrival-To-Origin Sliding Model Control for Multi-missile Systems," *2023 42nd Chinese Control Conference (CCC)*, Tianjin, China, 2023, pp. 129-133, doi: 10.23919/CCC58697.2023.10240566.

[11] J. Zhou, X. Nan, S. Wang and D. Zhao, "Distributed guidance design for multi-missile sequential attacks," *2022 IEEE International Conference on Unmanned Systems (ICUS)*, Guangzhou, China, 2022, pp. 578-583, doi: 10.1109/ICUS55513.2022.9986858.

[12] Hou, Z., Lan, X., Chen, H. *et al.* Finite-time Cooperative Guidance Law for Multiple Missiles with Impact Angle Constraints and Switching Communication Topologies. *J Intell Robot Syst* **108**, 85 (2023). https://doi.org/10.1007/s10846-023-01931-1.

[13] Zhang, M., Ma, J., Che, R., He, Y. (2022). Fixed-Time Convergence Cooperative Guidance Law Against Maneuvering Target. In: Yan, L., Duan, H., Yu, X. (eds) Advances in Guidance, Navigation and Control. Lecture Notes in Electrical Engineering, vol 644. Springer, Singapore. https://doi.org/10.1007/978-981-15-8155-7_332.

[14] Zhongyuan Chen, Xiaoming Liu, Wanchun Chen, Three-dimensional event-triggered fixed-time cooperative guidance law against maneuvering target with the constraint of relative impact angles, Journal of the Franklin Institute, Volume 360, Issue 6, 2023, Pages 3914-3966. https://doi.org/10.1016/j.jfranklin.2023.02.027.

# Cyberbullying Detection using Machine Learning and Deep Learning

Aljwharah Alabdulwahab[1], Mohd Anul Haq[2*], Mohammed Alshehri[3]

Department of Information Technology, College of Computer and Information Sciences,
Majmmah University, Al-Majmaah , Saudia Arabia.[1, 3]
Department of Computer Science, College of Computer and Information Sciences,
Majmaah University, Al-Majmaah, Saudi Arabia[2]

*Abstract*—With the human passion for gaining knowledge, learning new things and knowing the news that surrounds the world, social networks were invented to serve the human need, which resulted in the rapid spread and use among people, but social networks have a dark and bright side. The dark side is that strangers or anonymous people harass some users with obscene words that the user feels wrong about, which leads to psychological harm to him, and here we try to discover how to discover electronic bullying to block this alarming phenomenon. In this context, the utility of Natural Language Processing (NLP) is employed in the present investigation to detect electronic bullying and address this alarming phenomenon. The machine learning (ML) method is moderated based on specific features or criteria for detecting cyberbullying on social media. The collected characteristics were analyzed using the K-Nearest Neighbor (KNN), Support Vector Machine (SVM), Naive Bayes (NB), Decision Trees (DT), and Random Forest (RF) methods. Naturally, there are test results that use or operate on the proposed framework in a multi-category setting and are encouraged by kappa, classifier accuracy, and f-measure standards. These apparent outcomes show that the suggested model is a valuable method for predicting the behavior of cyberbullying, its strength, and its impact on social networks via the Internet. In the end, we evaluated the results of the proposed and basic features with machine learning techniques, which shows us the importance and effectiveness of the proposed features for detecting cyberbullying. We evaluated the models, and we got the accuracy of the KNN (0,90), SVM (0,92), and Deep learning (0,96).

*Keywords*—*Cyberbullying detection; machine learning; deep learning; natural language processing (NLP), feature extraction; CNN*

## I. INTRODUCTION

Cyberbullying is a severe cybersecurity concern that constantly affects more people using social media and the Internet. Bullying is arguably hostile behavior displayed by a single individual or a group of people, who can only be present in certain places or at certain times of the day (such as during school hours) and can alternatively occur everywhere and at any time through electronic methods.

Cyberbullying was not taken seriously at the turn of the 20th century when social media, in general, and Internet usage were still in their infancy. At the time, the optimistic advice for dealing with cyberbullying was to "disconnect" or "turn off the screen [1, 2]. However, when the effects of online hate speech

increase, these proposals lose their effectiveness. More than following the usual suggested cybersecurity standards and procedures is required to prevent cybercrime. 41% of American citizens reported experiencing online harassment personally in 2017, while 66% reported seeing discourse offensive to others. Additionally, about 50% of young individuals who use social media sites have been said to be various experience several kinds of cyberbullying. Popular social networking sites like Twitter are not immune to this menace.

The identification of cyberbullying has grown in importance as an NLP topic, cyberbullying detection's objective is like other NLP jobs. Entails preprocessing the text (like a tweet) and extracting critical information in a particular method. That enables the use of machine learning to understand and categorize each text. The classic methods for classifying text involve the use of a way to make text representation simpler, such as the bag-of-words (BoW) approach, then a machine learning classifier like the logistic regression (LR) or support vector machine (SVM) approach [3] (see Fig. 1).

Natural Language Processing (NLP), the field of artificial intelligence that focuses on the interaction between computers and human language, has made significant strides in identifying online abuse [3]. However, specific challenges persist, including limitations in accommodating long texts within the constraints of social media platforms, the imbalance between hostile and constructive comments, the inherent ambiguity of natural language, and the prevalent use of slang [4] in the past ten years, neural network-based models have outperformed conventional machine learning methods on several NLP tasks.
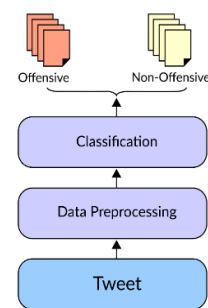


Fig. 1. The general framework of deep learning architecture.

*Corresponding Author

These NLP techniques rely on the successful use of word embeddings, specifically deep learning, and neural network dense vector representations. In contrast to conventional machine learning algorithm-based methods, which rely primarily on manually created characteristics that are viewed as insufficient Deep learning methods use multilevel automated feature representation, which is laborious, to distinguish the input. a model of a multilayer perceptron neural network in various NLP tasks, CNN-based models, and recurrent neural networks (RNN) have demonstrated promising outcomes and developed a novel character-based technique that combines a CNN model with an RNN architecture to categorize text. Long short-term memory (LSTM) categorizes phrases separately to learn text meaning; CNN then used word analysis to extract regional attributes.

Motivated by the notable results of numerous NLP research aiming to categorize extensive texts, deep learning systems have proved their effectiveness. This paper conducts a comprehensive examination of cyberbullying within social networks, employing advanced technologies and methodologies, including Natural Language Processing (NLP) and machine learning. In Section II, "Related Works," existing research is reviewed, offering insights into the techniques used to combat online harassment. Section III, "Materials and Methods," outlines the tools and strategies utilized, particularly NLP and machine learning. Section IV, "Computational Complexity," delves into the algorithms driving the cyberbullying detection system. Section V, "Results," presents the findings, emphasizing the method's high accuracy in predicting cyberbullying's impact on online social networks. Section VI, "Limitations and Future Scope," explores the study's boundaries and suggests future research directions. Finally, in Section VII, "Conclusions," the paper summarizes the implications of the research, shedding light on technology's role in enhancing online safety, and invites further exploration into these crucial issues.

## II. RELATED WORK

This section examines methods for detecting cyberbullying in online social networks (OSNs). Cyberbullying incidents were broken down into Race, sexual orientation, culture, and IQ are some of the categories that Dinakar et al. in [5]. They employed four distinct classifiers as a result (Naive Bayes (NB), grip with rules, J48 with trees, and SVM) to identify the comments submitted on several contentious YouTube videos as a use case. The dataset, which consists of over 50,000 words, consists of three sections: testing, validation, and training. The accuracy of Rule-based Jrip hasn't, however, exceeded 80% and this is a good percentage to reduce online bullying. A method to identify fine-grained cyberbullying techniques, such as insults and threats.

The authors referenced online bullying and content that was taken from Ask.FM website contains English and Dutch language features that are like OSNs. The authors divided the prospective participants between a cyberbullying discourse harasser, target, and onlooker—into three groups. Two groups were formed in the class: onlooker-defenders and bystander-assistants, who back the harasser while speaking up for the victim. The comments were then separated using SVMs.

However, bullying idioms are harder to locate in the text on Twitter. One of the first to provide a technique to identify cyberbullying on the Twitter network was Sanchez. et al. [6]. The authors used Twitter abuse against a specific gender was identified using an NB classifier. The accuracy of their approach, though, was only 70%, and the amount of the dataset they employed was modest. To include a wide range of examples of cyberbullying, the abusive models should be applied generally rather than only to one topic. Using word2vec as a feature representation approach and both NB and RF classifiers, Saravanarj et al. [7] provided a broad framework to identify false positives and abusive tweets. The framework may extract demographic data about the perpetrators, including They, also mentioned age, name, and gender. The recommended techniques, though, cannot generate precise outcomes in comparison to complex machine learning techniques like deep learning. This study achieved results of 78%.

The authors Al-garadi et al. [8] conducted a study to detect cyberbullying on Twitter, which takes advantage of several unique features, which explicitly include activity, network, user, and tweeting on the Twitter platform. For classification purposes, these traits, and the samples they were associated with were entered into a machine-learning system. According to the authors' analysis of four machine learning algorithms, the RF method is superior to all other algorithms in the area under the receiver operating characteristic curve and f-measurement such as KNN, SVM, and NB only about 599 out of 10007 authors. The dataset included total tweets related to bullying. The Big Five models (including neuroticism, agreeableness, and extraversion) and the Dark Triad (including psychopathy) have been used and I have achieved scores of 60%. by Balakrishnan, Khan, and Arabnia, Balakrishnan et al. [9,10]. To analyze the personalities of Twitter users and gradually spot online cruelty. The proposed method aimed to look at the connection between personality factors and online bullying. The writers divided the tweets into four categories representing the user's behavior: bully, spammer, attacker, and everyday person. Then the writers classified each tweet into one of the types mentioned earlier using the random forest RF ensemble approach. Results from the suggested system using these personality factors were favorable. Although it was a modest number, the dataset included 5453 tweets that were gathered using the hashtag "Gamergate." Additionally, the tweets are more specialized than they should be about a particular community (using the hashtag "Gamergate").

A significant amount of Twitter comments were examined by Chatzako et al. [11,12] to identify features of abusive conduct. These tweets were from people who engaged in various conversations, including those on the NBA, the Gamergate scandal, and comments about television programs about female wages. Discrepancy on stations run by the British Broadcasting Corporation (BBC). The writers looked into several aspects taken from Twitter, including user attributes, network-based features, and tweets. They then experimented with several cutting-edge classification techniques to differentiate across user accounts and achieved an accuracy of 91%.

A deep learning detection technique was presented by Gamback et al. [13] To recognize Twitter cyberbullying comments. The method divided the remarks into four categories: non-offensive, racist, sexist, and all three (i.e., sexism and racism). The authors used the character four grams to represent text. Word2vec was also employed for semantic analysis authors. After that, the authors used one of these methods to condense the feature set: Features of un-layer CNN (i.e., max-pooling layer). and they used a SoftMax method to classify each tweet as a result. When tested utilizing cross-validation by ten, the suggested approach had an F-score of 78.3%. Six thousand six hundred fifty-five tweets make up the datasets that the authors used to identify cyberbullying in Twitter comments.

Pradhan et al. [14] explored two deep learning architectures as well as a neural network model. The CNN-LSTM and CNN-BiLSTM Deep learning architectures and neural networks are two examples. Deep learning both methods yielded encouraging results, with an accuracy rate of about 92%. The efficiency of models for self-attention (these models obtained cutting-edge results in a variety of machine translation tasks) by Pradhan et al. [14], The detection of cyberbullying was investigated with the cyberbullying datasets from Form Spring, Wikipedia, and Twitter The application of the transformer architecture paradigm for self-attention was examined by the authors. A multiheaded self-attention layer was employed in this architecture to replace the recurrent layers that were utilized for encoding and decoding, the results from the suggested method were satisfactory.

Agrawal et al. [15] experimentally showed through a framework that this method could get around some of the drawbacks of previous approaches, such as limiting the limitation of hate speech identification to a specific category (i.e., cyberbullying) and using custom features available through traditional machine learning methods. To overcome these restrictions, the authors investigated four deep learning architectures: BiLSTM with an attention layer, CNN, and LSTM. Additionally, the authors categorize assault, bullying, racism, and sexism are four criteria used to classify hate speech on the social internet. Furthermore, they used transfer learning to apply the information gained from a deep understanding of two datasets, one of which was remarkably similar, extensive tests were conducted on the researched architectures using the Twitter, Wikipedia, and Formspring datasets. Around 16 thousand tweets from Twitter were used by the authors Pradhan et al. and Agrawal et al. [14,15] to identify social media cyberbullying using Spanish-language content, Plaza et al. [16] have devised a method. The authors investigated a few deep-learning algorithms to detect hate speech in Spanish. They were enhancing performance. The authors' deep learning models were trained. Specifically, used Transfer learning is used to address a few sample problems. Additionally, the authors evaluated how well SVM and LR are examples of standard machine learning techniques. Compared models of deep learning that have been pre-trained include the enhanced-BERT, LSTM, CNN, and LSTM. The trials demonstrated that using BERT techniques and pre-trained models together enhanced performance in terms of accuracy in comparison to

other deep learning and conventional models. Table I shows the comparison study of literature Review.

TABLE I.　COMPARISON STUDY OF LITERATURE REVIEW

| Authors | APP | Methods | Limitation | Accuracy |
|---|---|---|---|---|
| [5] | YouTube | Jrip, J48, NB, and SVM with rules | A small dataset with poor precision | 80% |
| [6] | Twitter | Classification NB | A small dataset with poor precision | 70% |
| [7] | Twitter | NB and random forests | Not reported | 78% |
| [8] | Twitter | KNN, RF, NB, and SVM | The dataset is not that large | 60% |
| [9,10] | Twitter | J48, RF, and NB | Constrained to a certain demographic with a fairly small dataset | 60% |
| [11,12) | Twitter | A probabilistic artificial neural network and ensemble | The dataset is not that large | 91% |
| [13] | Twitter | CNN uses SoftMax | The dataset is quite compact | 78.3% |
| [14] | Twitter, Wikipedia, and Formspring | CNN, LSTM, and SVM | There is a minimal amount of data | 92% |
| [15] | Twitter, Wikipedia, and Formspring | CNN, LSTM, and SVM | The dataset is quite compact | 92% |
| [16] | Twitter | BERT techniques and trained models | The data collection is not that large | 95% |

Motivated by the notable results of numerous NLP research aiming to categorize extensive texts, deep learning systems have proved their effectiveness. We look into the possibility of recognizing short sentences utilizing the multichannel deep learning model.

## III.　MATERIALS AND METHODS

### A. Dataset Description

The tweets dataset used in this study was sourced from [2] In two columns, the data includes tweets and class. The dataset has two types: cyberbullying and not cyberbullying. There were 47692 tweets utilized in total to create this dataset.

*1) Exploratory data analysis*: The table description of the Cyberbullying dataset. Table II displays the percentage of cyberbullying incidents, 38000 tweets however the percentage of cyberbullying incidents is 47692 tweets.

TABLE II.    CYBERBULLYING DATASET

| # | Column | Non-null Count | Dtype |
|---|--------|----------------|-------|
| 0 | Tweet_text | 47692 non-null | Object |
| 1 | Cyberbullying_type | 47692 non-null | Object |

According to Table II, the dataset's two columns are object types. In this dataset, 36 tweets were found to be duplicates; these tweets were eliminated. Eliminate contractions, emojis, new line characters, links, and stop words.

Remove just the "#" sign to maintain the center of the sentence's # hashtags while eliminating the # hashtags at the conclusion & and $ are filtered special characters that are present in some words. The words were also reduced in complexity via stemming. Stemming is a technique used to strip away the suffixes, prefixes, and other word elements of a given word until only its root or lemma remains. This approach is useful in NLP [17](see Fig. 2).

It was observed in Fig. 3 that the tweets (including very long tweets) ethnicity has reached less than 100. While in Fig. 4, the tweets (excluding very long tweets) ethnicity has reached less than 100, we conclude that most of the words in the tweets are bullying ethnicity and we must detect and limit these bad tweets to reduce bullying.
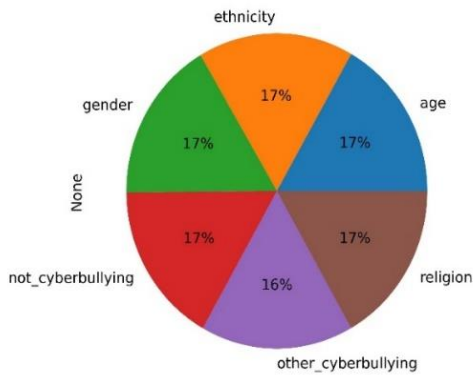


Fig. 2.    The proportion of cyberbullying.
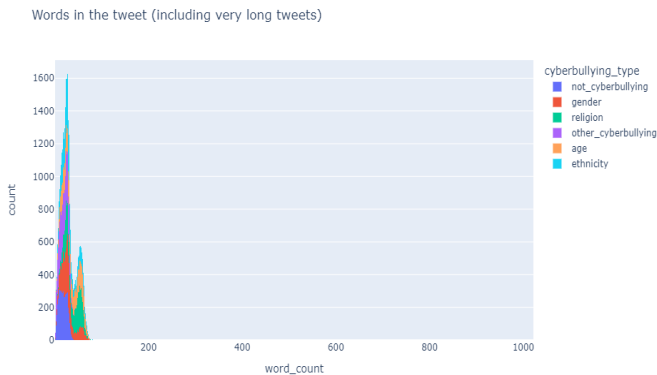


Fig. 3.    Words in the tweets, including very long tweets.
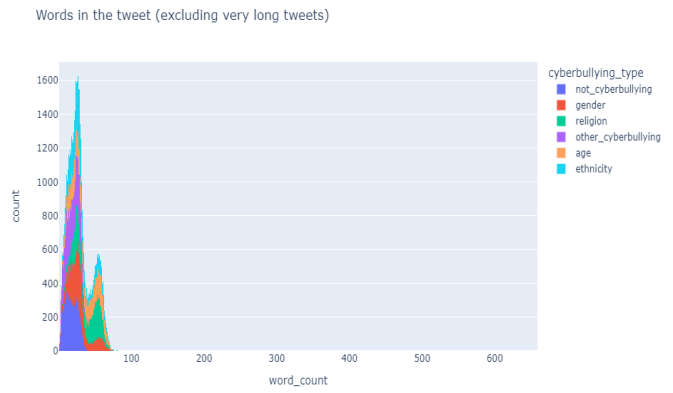


Fig. 4.    Words in the tweets, excluding very long tweets.

In the Fig. 5 shows the percentage of ages that are exposed to cyberbullying, which schools, where the percentage reached less than 9000, unlike kids, which shows that the percentage is less than 1000, and here it shows us what ages are affected by cyberbullying.

Fig. 6 shows the religion that is most exposed to cyberbullying, which is the Muslim, with a percentage of less than 5,000, in contrast to radical which shows a percentage is less than 2,000.
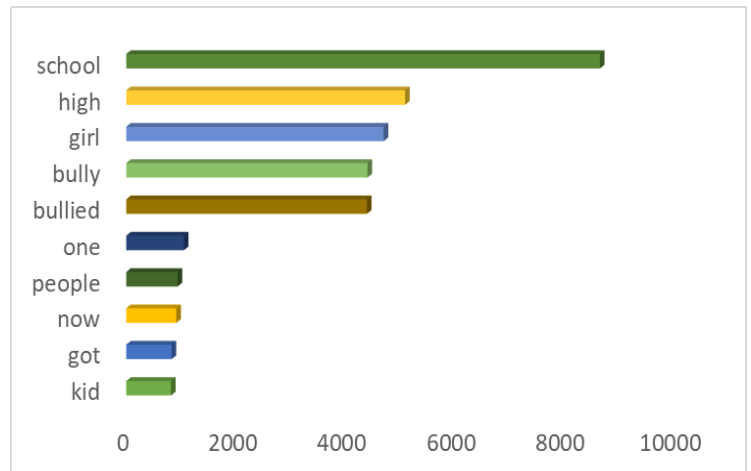


Fig. 5.    Age-based cyberbullying.
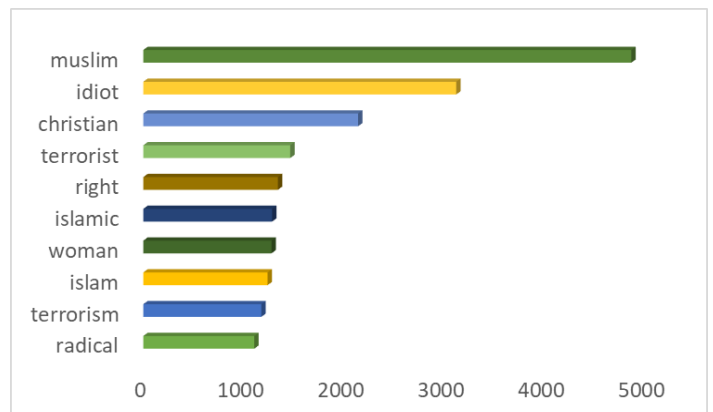


Fig. 6.    Religion-based cyberbullying.

## B. Evaluation Metrics

We also know that classification accuracy is the natural choice for statistics because identifying cyberbullying is a classification task, but we have a problem, which is the inequality in class for determining to cyberbully, and accuracy is not a reliable indicator, as well as retrieval and accuracy, as well as the F1 scale. To obtain all measures (TN) a matrix containing four categories of false positive (FP), false negative (FN), true positive (TP), and true negative values is used [18,19].

The fraction of correctly classified instances relative to all instances is known as accuracy. The Eq. (1) that follows determines it.

$$Accuracy = \frac{TP+TN}{TP+TN+FP+FN} \quad (1)$$

The recall is the proportion of correctly categorized examples that are positive when compared to instances that belong to the actual class. The Eq. (2) that follows determines it.

$$Recall = \frac{TP}{TP+TF} \quad (2)$$

The fraction of accurately categorized positive events relative to all projected positive instances is known as precision. The Eq. (3) that follows determines it.

$$Precision = \frac{TP}{TP+FP} \quad (3)$$

The F1 measure combines recall and precision, making it useful in situations when both are crucial. The Eq. (4) that follows determines it.

$$F1measure = 2 * \frac{(precision * recall)}{precision + recall} \quad (4)$$

## C. Methodology

*1) Feature extraction*: The sklearn package's CountVectorizer (CV), which has a 2500 feature maximum, was utilized to extract features. Cyberbullying type was used as a label, and a CV was added as a feature to the original tweet text. The label Y's size was 46017X6, and the feature X's was 46017X2500. With a ratio of 75:25 for training and testing, the data was divided using the sklearn train test split. The sklearn StandardScaler was used to conduct the feature scaling. The dataset was split into training and testing with a ratio of 75:25, therefore the training set contains 34512 records.

*2) KNN*: The k-nearest neighbor's algorithm is a supervised learning classifier that makes predictions or classifications about how a single data point will be grouped using proximity. Nevertheless, it can be used to address classification or regression problems. KNN compares data points based on how close or far apart they are from the query points. There are several ways to compute distance; one of the most popular is the Euclidean distance formula in Eq. (5).

$$d(x,y) = \sqrt{\sum_{i=1}^{n}(yi - xi)^2} \quad (5)$$

A straight line connecting the available location and the query point is measured by Euclidean distance.

KNN has the benefits of being simple to use, adaptable, and requiring fewer hyperparameters, but it also has memory and overfitting problems.

*3) Support vector machine*: Support Vector Machine (SVM), a dependable classification and regression technique, improves a model's projected accuracy while preventing overfitting the training set. SVM is especially effective for analyzing data that has thousands of predictor fields. By transforming the data into a high-dimensional subspace, SVM may categorize data points even when they are not linearly separable. After a class divider has been found, the data are transformed to allow for the separator's hyperplane.

*4) Deep learning model development*: We have developed a 6-layer Deep Learning model trained on the Twitter dataset for the identification of cyberbullying 5.2. This investigation used Python 3.8, Keras API, and Single-GPU TensorFlow 2.0 backend (i9, 10900k, 128 GB, 2666 MHz RAM). First, the Twitter dataset has been preprocessed. An embedding layer with the parameters vocab size and input length processes the input. The Embedding layer searches the vocabulary's integer encoding for each word's embedding vector. While the model is being trained, these vectors are learned, and the output array gains a dimension thanks to the vectors, (Batch, Sequence, and Embedding) are the measures that are obtained). The batch normalization layer was used to speed up and improve the stability of training artificial neural networks by normalizing the inputs to the layers by re-centering and re-scaling. The second layer was a convolution layer. By applying a filter to information, convolutional neural networks create a feature map that summarizes the existence of features recognized in the input. A max pool layer is made up of the third layer. The most significant value found in each patch of each feature map is determined using a pooling technique called max pooling. The results are feature maps that have been down-sampled or pooled, with the focus being placed on the feature that is most common in the patch as opposed to its average presence, as in the case of average pooling. A flattened layer, the fourth layer, condenses the input's spatial dimensions to only its channel dimension. For instance, the coating will produce a flattened (H*W*C)-by-N-by-S array if given an H-by-W-by-C-by-N-by-S array as input. The dense layer was the last two layers.

The dataset is categorized using a thick layer based on the output of the preceding layers. A non-linear function known as an "activation function" is applied to the weighted average of the input that the neurons in each neural network layer calculate. The initial dense layer with L1L2 regulators employed the ReLu activation function, while the final layer with the softmax function was used for classification. Fig. 7 displays the CNN-LSTM architecture that has been suggested for use in malware detection.

| embedding_input | input: | [(None, 2500)] |
|---|---|---|
| InputLayer | output: | [(None, 2500)] |

| embedding | input: | (None, 2500) |
|---|---|---|
| Embedding | output: | (None, 2500, 100) |

| conv1d | input: | (None, 2500, 100) |
|---|---|---|
| Conv1D | output: | (None, 2493, 32) |

| max_pooling1d | input: | (None, 2493, 32) |
|---|---|---|
| MaxPooling1D | output: | (None, 1246, 32) |

| flatten | input: | (None, 1246, 32) |
|---|---|---|
| Flatten | output: | (None, 39872) |

| dense | input: | (None, 39872) |
|---|---|---|
| Dense | output: | (None, 10) |

| dense_1 | input: | (None, 10) |
|---|---|---|
| Dense | output: | (None, 6) |

Fig. 7.   Proposed deep learning architecture for cyberbullying detection.

The model compilation followed the layer addition. An optimizer, a loss function, and a metric function are required to evaluate the model's validity during compilation. The stochastic gradient descent variant Adam optimization technique was used for optimization. It has several benefits, such as fewer memory requirements and quick calculations. Given that the label comprises six classes, the categorical cross-entropy loss function was utilized to quantify the error rate between the actual and values for binary classification.

## IV.   COMPUTATIONAL COMPLEXITY

Accuracy was then employed as an evaluation parameter. (6,739,628 params altogether, Trainable params: 6,739,628, non-trainable parameters: zero) as shown in  Table III.

TABLE III.    NUMBER OF TRAINABLE AND NON-TRAINABLE PARAMETERS FOR THE CNN-LSTM MODDLE

| Layer Type | Output Shape | #Params |
|---|---|---|
| embedding_1 (Embedding) | (None,2500, 100) | 6315200 |
| conv1d_1 (Conv1D) | (None,2493, 32) | 25632 |
| max_pooling1d_1 (MaxPooling 1D) | (None, 1246, 32) | 0 |
| flatten_1 (Flatten) | (None,39872) | 0 |
| dense_2 (Dense) | (None,10) | 398730 |
| dense_3 (Dense) | (None,6) | 66 |

In Table III the embedding layer has 6,315,200 parameters, which are used to map each of the 2,500 input tokens to a 100-dimensional vector. The complexity of this layer is O (batch_size * input_length * embedding_size) = O(32 * 2500 * 100) = O(8e7). The 1D convolutional layer has 25,632 parameters and requires batch_size * 2493 * 32 multiply-adds to produce its output. The complexity of this layer is O (batch_size * input_length * kernel_size * num_filters) = O (32 * 2493 * 3 * 32) = O(7.5e6). The max pooling layer simply reduces the output size by a factor of 2, so it has negligible computational complexity. The flattening layer has no parameters and simply reshapes the output of the previous layer, so it has negligible computational complexity. The first dense layer has 398,730 parameters and requires batch_size * 39872 multiply-adds to produce its output. The complexity of this layer is O (batch_size * input_size * output_size) = O (1.27e9). The second dense layer has 66 parameters and requires batch_size * 10 multiply-adds to produce its output. The complexity of this layer is O (batch_size * input_size * output_size) = O (3.2e3). The overall computational complexity of the given model can be approximated as O (1.36e9). This means that the computational cost of training and inference for this model grows linearly with the size of the input data. Specifically, the dominant factors contributing to the computational complexity of this model are the number of parameters in the embedding and dense layers, as well as the size of the input and output data for each layer.

## V.   RESULTS AND DISCUSSIONS

Here we review the accuracy results that were applied through the methods (KNN, SVM, Deep Learning) as shown in Table IV.

We note here that KNN gave fewer results than SVM and DL because of the approximation of the basic distribution of the data in a parametric way, and SVM assumes the existence of a super level that separates the data points from DL, as it is known that it works like a human neural network, as it is an effective classifier for cyberbullying detection tasks to extract text from how to create a 6-layer model.

Based on experiments, the deep learning method shows better results in accuracy for detecting cyberbullying than other methods (KNN, SVM), as deep learning is an effective classifier for cyberbullying detection tasks to extract text by creating a 6-layer model, which was A Twitter dataset drill was one GPU (i9, 10900K, 128GB 2666MHz RAM) running with Python 3.8, Keras API and Tensorflow 2.0 backend. The result indicated that deep learning achieved good state-of-the-art results on cyberbullying, and it is important to consider and analyze all results from all experiments.

To achieve our experiments, we applied a test to determine the appropriate resolution to deliver the best results for our model. Results using a deep learning algorithm to detect cyberbullying, in the first layer is embedding, which is the input processing and forms the output from (none, 2500, 100) and parameters 6315200 was made, the second layer is a wrapping layer and forms the output from (none, 2493, 32) and parameters 25632 was made, and the third layer takes the highest value found in Each patch and the results are reduced or aggregated feature maps that focus on the most prevalent

feature in the patch rather than its average presence and form the output from (none, 1246, 32) parameters 0, the fourth layer is a flat layer, where the flat layer minimizes The spatial dimensions of the inputs to their channel dimensions and form the output from (39872, none) and parameters 0 were made, and in the last two layers is the dense layer to enrich the data set by calculating the inputs of neurons in each layer and form the output from the first dense layer (none, 10) Parameters 398730 was created, the output was created from the second dense layer (none, 6), and parameters 66 was created.

It was noted that the accuracy (KNN) was (0.90), which means that the model correctly predicted 90% of the comments classified as cyberbullying. Let's assume that we have tweets and there is bullying. We will discover this bullying by asking about some characteristics or types of words. Here, the discovery is classified or programmed, so that it identifies bullying words and the way KNN works. We now have a word, and it has two properties (word, bad word) Can it be predicted for its classification, we determine the value of the variable that will express the number of neighbors k and let its value be k=3, we calculate the value of the distance through the Eq. (6).

$$d\,(x,y) = \sqrt{\sum_{i=1}^{n}(yi - xi\,)^2} \qquad (6)$$

Table IV represents the comparison of the present investigation with the existing studies used tweets datasets. Table IV. offers a valuable comparison with other studies in terms of accuracy and limitations or future scope. This table reinforces the significance of present research and the need for continuous improvement in the field of cyberbullying detection.

TABLE IV. COMPARISON WITH THE OTHER STUDIES

| Studies | Methods | Limitations/future scope | Accuracy |
|---|---|---|---|
| [6] | Classification NB | A small dataset with poor precision | 70% |
| [7] | NB and random forests | Not reported | 78% |
| [8] | KNN, RF, NB, and SVM | The dataset is not that large | 60% |
| [9,10] | J48, RF, and NB | Constrained to a certain demographic with a fairly small dataset | 60% |
| [11,12] | A probabilistic artificial neural network and ensemble | The dataset is not that large | 91% |
| [13] | CNN uses SoftMax | The dataset is quite compact | 78.3% |
| [14] | CNN, LSTM, and SVM | There is a minimal amount of data | 92% |
| [15] | CNN, LSTM, and SVM | The dataset is quite compact | 92% |
| [16] | BERT techniques and trained models | The data collection is not that large | 95% |
| Present Study | KNN | Will add more data as future endevour | 90% |
| Present | SVM | Will add more data as future endevour | 92% |
| Study | DL Model | Will add more data as future endevour | 96% |

Through this method, we can limit or meet the words of cyberbullying. Fig. 8 shows us the accuracy ratio between the methods (KNN= 0.90, SVM= 0.92, Deep Learning= 0,97), and here it is clear to us that Deep Learning is higher in accuracy than the rest.

Fig. 9 shows us the high accuracy of training over the ages, and that the validation accuracy rises with the exercise of accuracy as a direct relationship. The higher the accuracy of training, the higher the validation of accuracy, as well as the training loss and the loss of accuracy the graph shows us that the indicator is going down over the ages, the worse the training accuracy, the greater the loss.
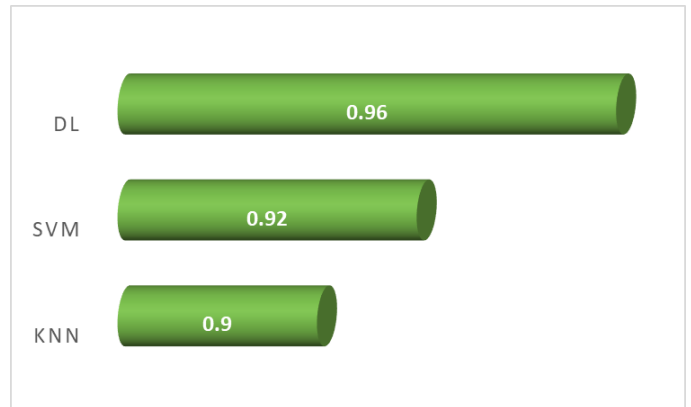


Fig. 8. The selected method and their accuracies.
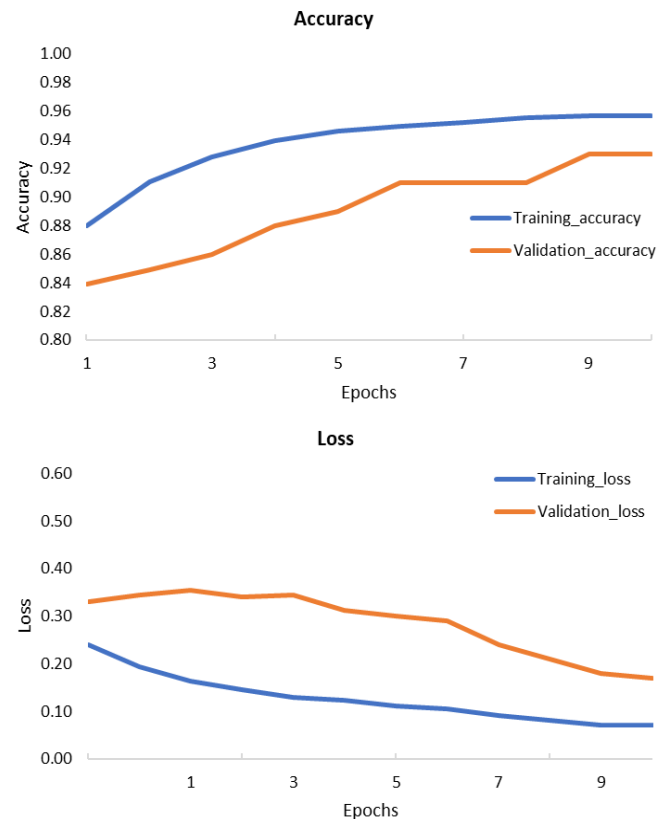


Fig. 9. Accuracy level through the epochs.

## VI. LIMITATIONS AND FUTURE SCOPE

As it is known that the KNN algorithm is simple and easy to understand, and the result of this ease is that it does not provide predictions for words that are not circulated or known among people because it has no idea about it, so we must know the bad words and update them between periods to update the bad words, and the KNN algorithm needs. A large memory to store a group of words or data to predict them that may be used in tweets, which requires that the memory be very large to store words [20]. SVM works by separating data, but it is not suitable for a large group of data, because it is not implemented well if the data is overlapping, and the kernel greatly affects the way SVM works, which must choose the best kernel that fits the data, as there is another limitation is that it uses a lot of memory, as it needs to store the kernel matrix, which can be large for the data set, and also SVM lacks a probabilistic interpretation to make a decision, which is a defect in some applications, and the last limitation we have is that SVM is sensitive to choosing parameters as it is difficult to determine the best parameter values for a set of data [21]. Deep learning faces a limitation, which is that it understands the words received in the training data, as it is possible that the person does not know all terms or words in all dialects, which affects the mechanism of deep learning, and it is known to use deep learning models devices. These devices help reduce time and increase Effectiveness, however, are very expensive and consume a lot of energy. One of the limitations of deep learning is the method of learning. Sometimes the process may be disrupted. If the method is low, it is difficult to find a solution [18, 21].

We intend to use more data when we implement our method. We believe expanding our sample will enhance our approach performance. Large data sets are necessary for deep learning algorithms to work effectively. We'll also attempt to expand the suggested structure by including numerous channels. The framework's performance might be enhanced by employing more media when using a large dataset. The weights and other parameters of deep and massive neural networks can be improved with a large dataset [22,23]. Additionally, we intend to test our suggested framework using tweets in several languages.

Looking ahead, promising avenues include the Reliable Architecture-Oblivious Error Detection (RAED) algorithm, which enhances the reliability of computer systems and contributes to user and system well-being [24-26]. SHA-3's role in data integrity verification and the Advanced Encryption Standard (AES) indirectly aid in preventing cyberbullying by ensuring data privacy and creating a safe online environment. Additionally, leveraging algorithms like SIKE and CSIDH enhances security and privacy on social media, ultimately contributing to a safer digital landscape and protection against cyberbullying [27-30].

## VII. CONCLUSIONS

The importance of online social networking has increased a part of our daily lives as it makes it easier to engage with others. However, detecting cyberbullying is an important topic to be examined due to the emergence of antisocial behavior faced by social media users due to issues such as hate speech, trolling, and cyberbullying on platforms such as Twitter and other social media experiences, which undoubtedly affects the psyche of victims. Social networks have become within the reach of everyone, especially children, and when children are exposed to electronic bullying, this affects the building of their personality and psyche. In this paper, reliable methods for detecting cyberbullying are presented. It shows how deep learning works and its high accuracy for detecting cyberbullying, and achieved the highest result, (0.96), by anticipating bad words, which helps reduce the spread of bullying in the means of communication, and as we mentioned another method, which is SVM, the result was good, which is (0.92). , but it is considered less than Deep learning, which affects the discovery of cyberbullying, and we also mentioned another method, which is KNN, which was the lowest result, as it achieved (0.90). The results show us the importance of this research and reliable methods to reduce the spread of cyberbullying.

### REFERENCES

[1] M. U. S. Khan, A. Abbas, A. Rehman, and R. Nawaz, "HateClassify: A Service Framework for Hate Speech Identification on Social Media," IEEE Internet Comput., vol. 25, no. 1, pp. 40–49, Jan. 2021, doi: 10.1109/MIC.2020.3037034.

[2] J. Wang, K. Fu, and C. T. Lu, "SOSNet: A Graph Convolutional Network Approach to Fine-Grained Cyberbullying Detection," Proc. - 2020 IEEE Int. Conf. Big Data, Big Data 2020, pp. 1699–1708, Dec. 2020, doi: 10.1109/BIGDATA50022.2020.9378065.

[3] M. A. Haq, M. Abdul, R. Khan, and T. Al-Harbi, "Development of PCCNN-Based Network Intrusion Detection System for EDGE Computing," Computers, Materials & Continua", vol.71, no.1, 2022 doi: 10.32604/cmc.2022.018708.

[4] O. Gencoglu, "Cyberbullying Detection with Fairness Constraints," IEEE Internet Comput., vol. 25, no. 1, pp. 20–29, Jan. 2021, doi: 10.1109/MIC.2020.3032461.

[5] K. Dinakar, R. Reichart, and H. Lieberman, "Modeling the detection of textual cyberbullying," AAAI Work. - Tech. Rep., vol. WS-11-02, pp. 11–17, 2011, doi: 10.1609/icwsm.v5i3.14209.

[6] H. Sanchez and S. Kumar, "Twitter Bullying Detection Knowledge Maps (KMs) View project The Vesperin System View project Twitter Bullying Detection", Accessed: Mar. 29, 2023. [Online]. Available: https://www.researchgate.net/publication/267823748

[7] A. Saravanaraj, J. I. Sheeba, and S. P. Devaneyan, "Automatic Detection of Cyberbullying From Twitter," IRACST-International J. Comput. Sci. Inf. Technol. Secur., vol. 6, no. 6, pp. 2249–9555, 2019, [Online]. Available: https://www.researchgate.net/publication/333320174

[8] M. A. Al-Garadi, K. D. Varathan, and S. D. Ravana, "Cybercrime detection in online communications: The experimental case of cyberbullying detection in the Twitter network," Comput. Human Behav., vol. 63, pp. 433–443, Oct. 2016, doi: 10.1016/J.CHB.2016.05.051.

[9] V. Balakrishnan, S. Khan, T. Fernandez, and H. R. Arabnia, "Cyberbullying detection on twitter using Big Five and Dark Triad

features," Pers. Individ. Dif., vol. 141, no. January, pp. 252–257, 2019, doi: 10.1016/j.paid.2019.01.024.

[10] V. Balakrishnan, S. Khan, and H. R. Arabnia, "Improving cyberbullying detection using Twitter users' psychological features and machine learning," Comput. Secur., vol. 90, p. 101710, 2020, doi: 10.1016/j.cose.2019.101710.

[11] D. Chatzakou, N. Kourtellis, J. Blackburn, E. De Cristofaro, G. Stringhini, and A. Vakali, "Mean birds: Detecting aggression and bullying on Twitter," WebSci 2017 - Proc. 2017 ACM Web Sci. Conf., pp. 13–22, Jun. 2017, doi: 10.1145/3091478.3091487.

[12] D. Chatzakou et al., "Detecting Cyberbullying and Cyberaggression in Social Media," ACM Trans. Web, vol. 13, no. 3, Oct. 2019, doi: 10.1145/3343484.

[13] B. Gambäck and U. K. Sikdar, "Using Convolutional Neural Networks to Classify Hate-Speech," Proc. Annu. Meet. Assoc. Comput. Linguist., pp. 85–90, 2017, doi: 10.18653/V1/W17-3013.

[14] A. Pradhan, V. M. Yatam, and P. Bera, "Self-Attention for Cyberbullying Detection," 2020 Int. Conf. Cyber Situational Awareness, Data Anal. Assessment, Cyber SA 2020, Jun. 2020, doi: 10.1109/CYBERSA49311.2020.9139711.

[15] S. Agrawal and A. Awekar, "Deep learning for detecting cyberbullying across multiple social media platforms," Lect. Notes Comput. Sci. (including Subser. Lect. Notes Artif. Intell. Lect. Notes Bioinformatics), vol. 10772 LNCS, pp. 141–153, 2018, doi: 10.1007/978-3-319-76941-7_11/COVER.

[16] F. M. Plaza-del-Arco, M. D. Molina-González, L. A. Ureña-López, and M. T. Martín-Valdivia, "Comparing pre-trained language models for Spanish hate speech detection," Expert Syst. Appl., vol. 166, p. 114120, Mar. 2021, doi: 10.1016/J.ESWA.2020.114120.

[17] M. A. Haq, M. Abdul, and R. Khan, "DNNBoT: Deep Neural Network-Based Botnet Detection and Classification A ROBUST VIDEO STABILIZATION ALGORITHMS FOR GLOBAL MOTION ESTIMATION USING BLOCK MATCHING View project A Futuristic Analysis Approach of Neural Network for Intrusion Detection System. View project DNNBoT: Deep Neural Network-Based Botnet Detection and Classification", doi: 10.32604/cmc.2022.020938.

[18] M. Anul Haq and C. Author, "CNN Based Automated Weed Detection System Using UAV Imagery Coupling GPR Measurements and Modelling for Mountain Glacier Volume Assessment in India and Russia View project Understanding the Geomorphology of Martian Surface using MoM Datasets View project CNN Based Automated Weed Detection System Using UAV Imagery", doi: 10.32604/csse.2022.023016.

[19] M. Anul Haq and C. Author, "SMOTEDNN: A Novel Model for Air Pollution Forecasting and AQI Classification Modeling the snow properties for their classification and identification View project

[20] M. A. Haq et al., "Analysis of environmental factors using AI and ML methods," Sci. Reports |, vol. 12, p. 13267, 123AD, doi: 10.1038/s41598-022-16665-7.

[21] M. Anul Haq and C. Author, "CDLSTM: A Novel Model for Climate Change Forecasting Understanding the Geomorphology of Martian Surface using MoM Datasets View project Development of Glacial Lake Monitoring Techniques in The Uttarakhand Himalayas Using Geomatics Techniques View project CDLSTM: A Novel Model for Climate Change Forecasting", doi: 10.32604/cmc.2022.023059.

[22] M. Anul Haq, "DBoTPM: A Deep Neural Network-Based Botnet Prediction Model," 2023, doi: 10.3390/electronics12051159.

[23] M. A. Haq, M. A. R. Khan, and M. Alshehri, "Insider Threat Detection Based on NLP Word Embedding and Machine Learning," Intell. Autom. Soft Comput., vol. 33, no. 1, pp. 619–635, Jan. 2022, doi: 10.32604/IASC.2022.021430.

[24] M. M. Kermani and R. Azarderakhsh, "Reliable Architecture-Oblivious Error Detection Schemes for Secure Cryptographic GCM Structures," IEEE Trans. Reliab., vol. 68, no. 4, pp. 1347–1355, 2019, doi: 10.1109/TR.2018.2882484.

[25] M. Mozaffari-Kermani and A. Reyhani-Masoleh, "Reliable hardware architectures for the third-round SHA-3 finalist Grøstl Benchmarked on FPGA platform," Proc. - IEEE Int. Symp. Defect Fault Toler. VLSI Syst., pp. 325–331, 2011, doi: 10.1109/DFT.2011.60.

[26] M. Mozaffari-Kermani and A. Reyhani-Masoleh, "A Structure-independent Approach for Fault Detection Hardware Implementations of the Advanced Encryption Standard," pp. 47–53, 2008, doi: 10.1109/fdtc.2007.15.

[27] B. Koziel, A. B. Ackie, R. El Khatib, R. Azarderakhsh, and M. M. Kermani, "SIKE'd Up: Fast Hardware Architectures for Supersingular Isogeny Key Encapsulation," IEEE Trans. Circuits Syst. I Regul. Pap., vol. 67, no. 12, pp. 4842–4854, 2020, doi: 10.1109/TCSI.2020.2992747.

[28] M. Anastasova, R. Azarderakhsh, and M. M. Kermani, "Fast Strategies for the Implementation of SIKE Round 3 on ARM Cortex-M4," IEEE Trans. Circuits Syst. I Regul. Pap., vol. 68, no. 10, pp. 4129–4141, 2021, doi: 10.1109/TCSI.2021.3096916.

[29] A. Jalali, R. Azarderakhsh, M. M. Kermani, and D. Jao, "Towards Optimized and Constant-Time CSIDH on Embedded Devices," Lect. Notes Comput. Sci. (including Subser. Lect. Notes Artif. Intell. Lect. Notes Bioinformatics), vol. 11421 LNCS, pp. 215–231, 2019, doi: 10.1007/978-3-030-16350-1_12.

[30] M. Mozaffari-Kermani, R. Azarderakhsh, and A. Aghaie, "Reliable and Error Detection Architectures of Pomaranch for False-Alarm-Sensitive Cryptographic Applications," IEEE Trans. Very Large Scale Integr. Syst., vol. 23, no. 12, pp. 2804–2812, 2015, doi: 10.1109/TVLSI.2014.2382715.

# Modified Deep Neural Network for Object Recognition

Dulari Bhatt[1], Chirag Patel[2*], Madhuri Chopade[3], Madhvi Dave[4], Chintan Patel[5]

Research Scholar, Computer Science & Engineering, Parul University, Vadodara, Gujarat, India[1]
Associate Professor, Computer Science, Charusat University, Gujarat, India[2]
Assistant Professor, Information Technology, Gandhinagar University, Gujarat, India[3]
Associate Professor, Computer Science, Adani Institute of Digital Technology Management, Gujarat, India[4]
Academic Associate, IIM Ahmedabad, Gujarat, India[5]

*Abstract*—Object recognition has gained significance due to the rise in CCTV surveillance and the need for automated detection of objects or activities in images and videos. Lightweight process frameworks are in demand for sensor networks. While Convolutional Neural Networks (CNNs) are widely used in computer vision, many existing architectures are specialized. This paper introduces the Dimension-Based Generic Convolution Block (DBGC), enhancing CNNs with dimension-wise selection of kernels for improved performance. The DBGC offers flexibility for height, width, and depth kernels and can be applied to different dimension combinations. A key feature is the dimension selector block. Unoptimized kernel dimensions reduce computational operations and accuracy, while semi-optimized ones maintain accuracy with fewer operations. Optimized dimensions provide 5-6% higher accuracy and reduced operations. This work addresses the challenge of generic architecture in object recognition research.

*Keywords—Convolutional Neural Network (CNN); depth-wise separable convolution; dimension-based generic convolution unit (DBGC); CNN architecture*

## I. INTRODUCTION

The Convolutional Neural Network (CNN) stands as a widely adopted architecture within the realm of computer vision, serving pivotal roles in tasks like object recognition and detection [1]. Researchers have delved into a myriad of modifications for CNNs in the past, encompassing areas such as activation functions, regularization techniques, parameter tuning, and architectural advancements. In the following section, we will delve into the latest developments in this ever evolving field.

This paper introduces a groundbreaking innovation known as the Dimension-Based Generic Convolution Unit (DBGC), which operates as a dimension selector module. Remarkably versatile, the DBGC can be seamlessly integrated into various architectural frameworks, yielding reductions in Floating Point Operations Per Second (FLOPs) without compromising accuracy. The research makes a significant contribution by presenting both semi-optimized and fully optimized kernel methods, effectively curtailing FLOPs while either maintaining or improving model accuracy.

The applications of computer vision and image processing extend across a multitude of domains, including but not limited to traffic surveillance, object detection, autonomous vehicles, agriculture, and healthcare [2], [3]. A crucial aspect of computer vision tasks is precise feature extraction. Fusion methods for feature extraction, as mentioned in b4 [4], enhance performance. The paper identifies inspiration from networks like ShuffleNetv2 [5], ESPNetv2 [6], DiCENet [7], and MobileNetv2 [8]. The subsequent sections elaborate on these networks' core architectures, strengths, and weaknesses.

### A. ShuffleNetv2

ShuffleNetv2, presented in the 2018 paper "ShuffleNetv2: Practical Guidelines for Efficient CNN Architecture Design" by Ma, Zhang, Zheng, and Sun, introduces a novel approach for evaluating computational complexity [5]. In addition to the conventional FLOPs metric, ShuffleNetv2 considers factors like speed, memory access costs, and platform-specific parallelism. Unlike FLOPs alone, which may not accurately reflect network speed due to variables such as memory access and target platform differences, this approach provides a more comprehensive assessment of efficiency. To address these limitations, ShuffleNetv2 introduces four key principles for network design:

- Proportional Input and Output Channels: Maintaining a 1:1 ratio between input and output channels minimizes memory access costs.

- Optimal Group Convolution: Carefully selecting the number of groups in convolutions prevents excessive memory access costs.

- Reduced Network Fragmentation: Minimizing network fragmentation enhances parallelism efficiency for better parallel computations.

- Significance of Element-wise Operations: Despite low FLOPs, element-wise operations can significantly increase memory access time.

The combined application of these principles enhances CNN architecture efficiency beyond FLOPs considerations. ShuffleNetv2 integrates these principles into its design to improve network efficiency, as illustrated in Fig. 1.

### B. ESPNetv2

ESPNetv2 is a progression from ESPNetv1, initially designed for semantic segmentation [6]. It broadens the application of ESPNetv1's ideas to diverse computer vision tasks, even encompassing language modeling. The central aim

---

*Corresponding Author

is refining the separation of dilated convolutions in a depth-wise fashion. This is realized through the introduction of a new module called EESP (Extremely Efficient Spatial Pyramid), outlined in Fig. 2.

The EESP block in ESPNetv2 divides channels into two groups, using one as an identity and maintaining channel balance during convolutions. It avoids group-wise convolutions and includes ReLU concatenations and depth-wise convolutions [6]. The architecture begins with stride-2 convolutions and has three phases, each starting with a stride EESP block, altering spatial dimensions and channels. Afterward, there are convolution layers, global average pooling, and a classifier. Strided EESP uses dilated convolutions and concatenation for long-range connections, supported by depth-wise convolutions for spatial information. ESPNetv2 achieves about 74% Top1 accuracy with 5.9 million parameters.
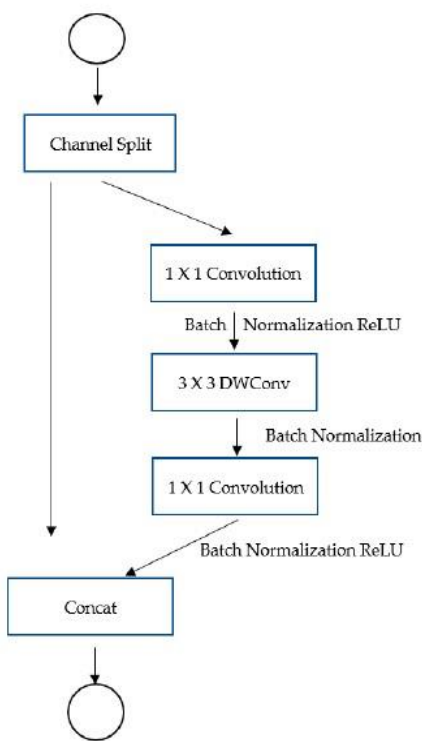


Fig. 1. ShuffleNetv2 design.
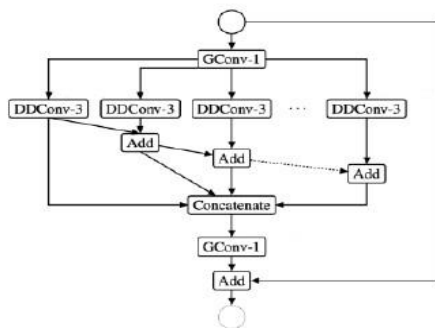


Fig. 2. Building block of EESP.

### C. DiCENet

DiCENet introduces the concept of dimension-wise convolution and fusion to replace regular convolution. Depth wise and group convolutions divide the input tensor along the channel dimension, allowing each filter to operate on specific channel subsets [7]. DiCENet suggests extending this slicing approach to width and height dimensions. Depth-wise convolution has a drawback of requiring multiple convolutions to effectively mix channels, constituting a substantial portion of operations in models like MobileNet.

ShuffleNet attempted to mitigate this with grouped convolution for speed, but further improvement might be possible. DiCENet proposes dimension-wise convolution (DimConv) across all three possible axes (DHW): depth-wise (HW), widthwise (DH), and height-wise (DW). Depth-wise covers spatial dimensions, widthwise involves splitting along channels while sliding over image width, and height-wise does the same along the height axis. This approach aims to enhance convolution efficiency and performance.

### D. MobileNetv2

MobileNetv2 maintains the use of depth-wise convolution, a characteristic shared with its predecessor, MobileNetv1 [8]. However, in MobileNetv2, the arrangement of blocks is restructured, notably placing the depth-wise convolution block at the center, as depicted in Fig. 3. Preceding the depth wise layer is a 1x1 convolution referred to as the expansion layer, which augments the channel count. Following the depth wise layer, there is another 1x1 convolution, identified as the projection layer or bottleneck layer. This final convolution reduces the number of channels back to a more optimal configuration. This architectural adjustment aims to enhance the model's performance and efficiency.

MobileNetv2 retains the depth-wise convolution approach from its predecessor, MobileNetv1 [8]. However, MobileNetv2 introduces a novel block arrangement. Notably, it places the depth-wise convolution block at the center, as shown in Fig. 3. Preceding the depth-wise layer is a 1x1 convolution known as the expansion layer, which increases channel numbers. Subsequent to the depth-wise layer, another 1x1 convolution, called the projection or bottleneck layer, is employed. This final convolution reduces channel counts to an optimal level. This architectural shift is designed to boost both the performance and efficiency of the model.

MobileNetv2 preserves ReLU6 as its activation function, as in its predecessor. Yet, beyond the bottleneck layer, it opts not to use any activation function [8], termed "linear bottlenecks." This choice is informed by the risk of losing vital information due to non-linearity in this low-dimensional data context.

Together, these elements constitute the architecture of MobileNetV2. Subsequently, the architecture involves a conventional 1x1 convolution layer, global average pooling, and a classification layer, as depicted in Fig. 3. Fig. 4 furnishes the Top1 and Top5 accuracy metrics for a range of lightweight CNN architectures.
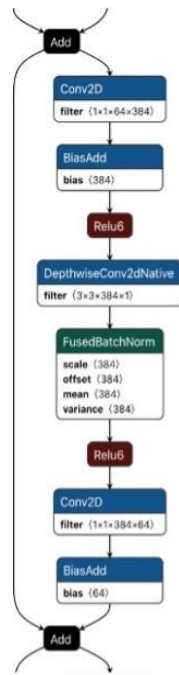
Fig. 3.  MobileNetv2.

| Architecture | Year | Parameters | Top1 | Top5 |
|---|---|---|---|---|
| ShuffleNetv2 [6] | 2018 | 2.3 M | 69.4 | 88.9 |
| MobileNetv2 [7] | 2018 | 3.47 M | 71.8 | 91.0 |
| ESPNetv2 [8] | 2019 | 3.49 M | 72.06 | 90.39 |
| DiCENet [9] | 2020 | 2.65 M | 69.05 | 88.8 |

Fig. 4.  A comparison of different lightweight architectural designs.

In Section III of the manuscript, the authors present the DBGC (Dimension-based Generic Convolution) block. A comprehensive grasp of the concepts expounded upon in Section II is essential for a complete comprehension of this section. Section II is bifurcated into two key segments: the initial part elucidates the separable convolution technique and its diverse modifications, while the subsequent part delves into an array of convolutional kernels. Moving forward, Section IV provides a detailed examination of the results and analysis pertaining to the recently introduced DBGC block.

## II. MATERIALS AND METHODS

This section provides a clear explanation of crucial terminologies and their relevance in the context of the proposed DBGC block. The section is structured into two subsections: the first one covers separable convolution, while the second one delves into depth-wise separable convolution.

### A. Introduction to Separable Convolution

The inception of separable convolution dates back to the Xception model of 2016 [9]. In response to the growing trend of deep learning (DL) moving towards edge computing, especially on smart phones and IoT devices, researchers proposed various techniques to enhance inferential computation efficiency. These techniques encompass network pruning, parameter compression, and more. One particularly effective approach is quantization, which streamlines DL processes by enabling them to operate on fixed-point pipelines. The renowned lightweight architecture,

MobileNetv1, has notably leveraged separable convolution to substantially reduce parameter size and computation latency [9].

Separable convolutions can be categorized into two main types: (1) Spatial separable convolution and (2) Depth-wise separable convolution.

*1) Spatial separable convolution*: Spatial separable convolution simplifies convolution by breaking it into two separate convolutions [18]. While conceptually straightforward, its practical application in deep learning is limited due to certain drawbacks. The term "spatial separable convolution" reflects its focus on width and height dimensions in images and kernels [10], with image channels representing the "depth" dimension. This approach splits a kernel into smaller parts; for example, a 3x3 kernel is divided into 3x1 and 1x3 kernels, as shown in Fig. 5.

$$\begin{bmatrix} 2 & 4 & 6 \\ 3 & 6 & 9 \\ 4 & 8 & 12 \end{bmatrix} = \begin{bmatrix} 2 \\ 3 \\ 4 \end{bmatrix} X \begin{bmatrix} 1 & 2 & 3 \end{bmatrix}$$

Fig. 5.  Dividing a 3x3 kernel into spatial.

Achieving the same outcome involves conducting two convolutions, each with three multiplications, totaling six, as opposed to a single convolution with nine multiplications. This approach reduces computational complexity by minimizing the number of multiplications, resulting in enhanced network efficiency, as illustrated in Fig. 6.

A notable limitation of a spatial separable kernel is its inability to effectively divide all kernels into two parts. This limitation becomes particularly problematic during training, as it utilizes only a small fraction of the entire network.

*2) Depth-wise separable convolution*: When working with kernels that cannot be decomposed into smaller components, the adoption of depth-wise separable.
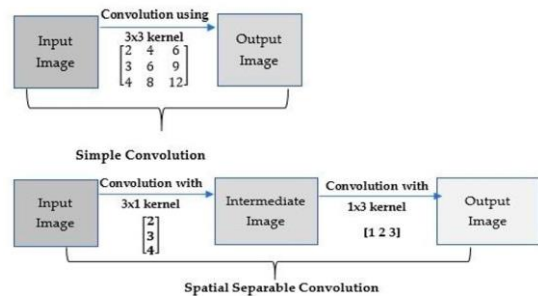


Fig. 6.  Basic and spatially separable convolution.

Convolution becomes increasingly popular. Facilitating its implementation are tools such as keras.layers.SeparableConv2D or tf.layers.separable$_c$onv2d. The term "depth-wise separable convolution" reflects its attention to both spatial dimensions and the depth dimension (number of channels) [11]. In an input image with RGB channels, each channel (R, G, B) provides a distinct interpretation of the image. After multiple convolutions, the image can comprise a variety of channels [12]. For instance, the "red" channel focuses on redness, "blue" on blueness, and

"green" on greenness. A 64-channel image can be understood in 64 unique ways. In depth-wise separable convolution, similarly to spatial separable convolution, a kernel is divided into two separate kernels. One kernel handles depth-wise convolution, while the other manages point-wise convolution.

*a) Depth-Wise Convolution*: Depth-wise convolution applies convolutional kernels to an input image without modifying its depth, as elucidated in [13]. This process, illustrated in Fig. 7, is achieved through the utilization of three distinct kernels. For example, when dealing with a 12x12x3 input image, three 5x5x1 kernels are employed. Each 5x5x1 kernel traverses a channel of the input image, computing scalar products for every group of 25 pixels (5x5). Consequently, this generates an output image of dimensions 8x8x1, as visually depicted in Fig. 7.
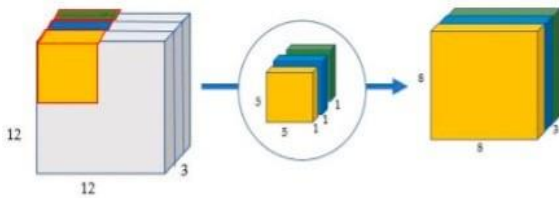


Fig. 7.   Depth-wise convolution employs three kernels to transform a $12 \times 12 \times 1$ image into an $8 \times 8 \times 1$ image.

*b) Point-Wise Convolution*: Following depth-wise convolution, the image transforms from 12x12x3 to 8x8x3, necessitating a channel expansion. "Point-wise convolution" uses a 1x1 kernel, processing individual points. The kernel's depth matches input image channels [14]. For an 8x8x1 result, a 1x1x3 kernel moves through the 8x8x3 image, as shown in Fig. 8.
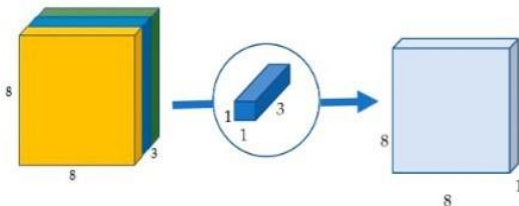


Fig. 8.   Point-wise convolution reduces a three-channel image to a single-channel image.

In a normal convolution, considering 256 kernels of 5x5x3 over 8x8 movements requires 1,228,800 multiplications. In separable convolution, using three 5x5x1 kernels for depth wise convolution in 8x8 movements entails 4,800 multiplications, and point-wise convolution with 256 kernels of 1x1x1x3 needs 49,152 multiplications. The total is 53,952.

Comparatively, 1,228,800 is significantly higher than 53,952. Fewer calculations enable efficient data processing. Standard convolution alters the image 256 times, demanding 4,800 multiplications each. In contrast, separable convolution modifies the image once and extends it to 256 channels, conserving resources. Separable convolution's limitation is minimizing parameters, potentially affecting small networks. Nonetheless, it boosts efficiency without compromising effectiveness, making it a popular choice20.

### B. Introduction to Convolution Kernels

Convolution utilizes a matrix-like "kernel" to extract targeted "features" from an input image, enhancing the output through multiplication, as shown in Fig. 9. For instance, a kernel can sharpen the input image, yielding a desired output representation [20].
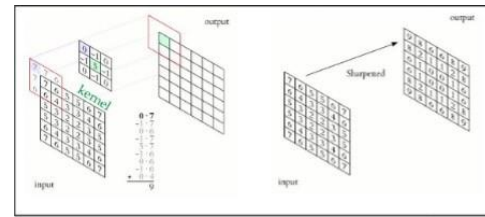


Fig. 9.   Example for convolutional use kernel.

Convolution involves using a "kernel," a matrix of weighted values, to extract important features from input data. The term "convolution" is related to the dimensions of the kernel, such as in 2D convolutions where the kernel matrix is two dimensional. On the other hand, a "filter" is a collection of multiple kernels, each applied to a specific input channel. Filters have an extra dimension compared to kernels, particularly in 2D convolutions, where filters become 3D matrices. For a CNN layer with kernel dimensions of h*w and input channels of k, filter dimensions become k*h*w. Convolutions come in three types based on kernel nature: 1D, 2D and 3D convolutions.

*1) 1D convolution*: 1D convolutions are highly useful for processing time series data, especially with one-dimensional inputs, even when containing multiple channels [15]. These convolutions operate in a single direction, resulting in one-dimensional output, as demonstrated in Fig. 10.
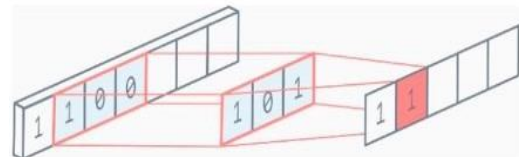


Fig. 10.  1D convolution.

*2) 2D Convolution*: In 2D convolutions, as shown in Fig. 11, the kernel size is 3x3. Multiple kernels, highlighted in yellow, form a filter that corresponds to various input channels indicated in blue. Each channel aligns with a distinct kernel. The filter moves in two directions across the input, resulting in a two-dimensional output. 2D convolutions are widely used, particularly in computer vision.
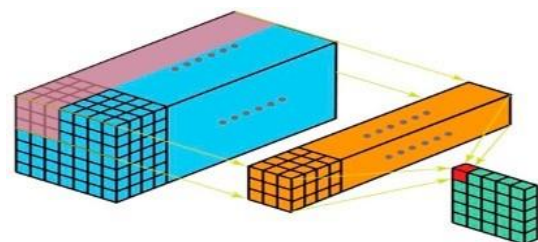


Fig. 11.  2D convolution.

*3) 3D Convolution*: Visualizing a 3D filter (4D matrix) can be complex. However, we'll focus on single-channel 3D convolution for simplicity. As shown in Fig. 12, the kernel moves in three directions, leading to a 3D output [16]. It's notable that most customization and modification research for CNN layers has primarily concentrated on 2D convolutions.
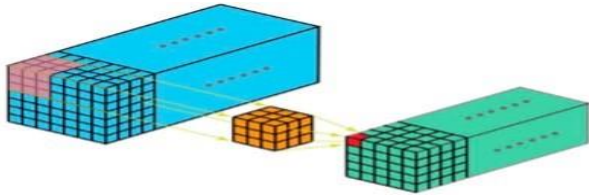


Fig. 12. 3D convolution.

## III. DBGC: DIMENSION-BASED GENERIC CONVOLUTION

Standard convolutions simultaneously handle spatial and channel data but can be computationally demanding. To improve efficiency, separable convolutions split spatial and channel data via depth-wise and point-wise convolutions, yet this can lead to computational bottlenecks in point-wise convolutions. The DBGC unit addresses this by using a dimension selector to efficiently encode spatial and dimension information, reducing computational load. Fig. 13 shows DBGC architecture. This involves two stages illustrated in Fig. 9: dimension-based convolution Section III(A) and dimension-wise fusion Section III(C). By replacing point-wise convolutions with dimension-based ones, the DBGC unit alleviates computational bottlenecks.

### A. Convolution based on Dimension (ConvDim)

The ConvDim block processes information distinctly along the height-wise, depth-wise, and width-wise dimensions. To achieve this, it extends the concept of depth-wise separable convolutions to encompass all dimensions of the input tensor I, which is characterized by dimensions $H \times D \times W$ (representing height, depth, and width). As illustrated in Figure 12, ConvDim employs three sets of kernels for each dimension: KH for height-wise convolution, KD for depth-wise convolution, and KW for width-wise convolution. These dimension-specific kernels generate outputs denoted as YH, YD, and YW, each having dimensions $H \times D \times W$, effectively capturing information from the input tensor. Subsequently, these outputs are amalgamated within the dimension selector block, merging spatial planes to yield the ultimate output, YDim.
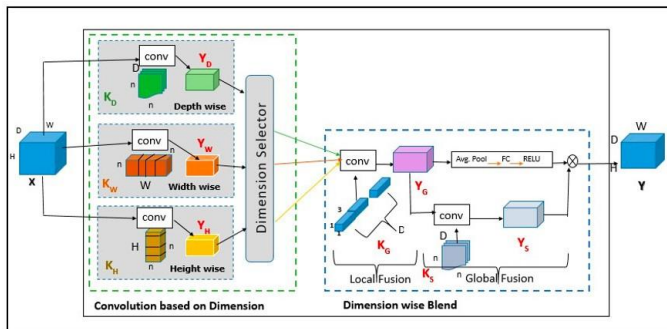


Fig. 13. DBGC architecture.

### B. Dimension Selector (Ds)

The dimension selector block, labeled as Ds, allows dimension selection tailored to specific application needs. Depending on requirements, users can opt to use only height, width, or depth dimensions during training. Parameters in this block specify chosen dimensions: Ds = KD, KW, KH. Combinations of two kernels are also possible, such as Ds = KD, KW, Ds = KH, KW, Ds = KD, KH, and Ds = KD, KW, KH. Thus, the dimension selector presents seven possibilities: height-only, width-only, depth-only, height and width, width and depth, height and depth, and all three dimensions. Selected kernels influence YDim integration, showcased in various dimension combinations in Fig. 14.

### C. Dimension-Wise Blends (DimBlend)

Dimension-wise convolutions capture local information from input tensor dimensions, but not global information. While point-wise convolutions in CNNs commonly combine global insights, they can be time-consuming. To address this, the dimension-wise blend module (DimBlend) divides pointwise convolution into local and global fusion phases, effectively merging dimension-wise representations from YDim into output Y [6]. The dimension-wise blend module, DimBlend, offers an alternative by splitting the point-wise convolution into two phases, as shown in Fig. 14.
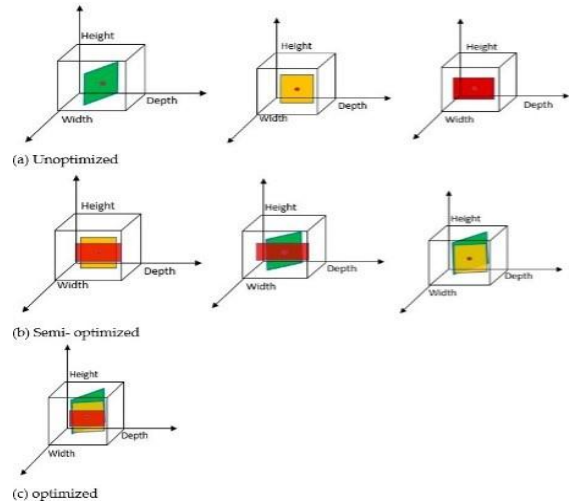


Fig. 14. ConvDim implementation progresses from individual kernel application (a) to simultaneous application of two kernels (b) and finally to concurrent application of all kernels (c), efficiently aggregating information through height-wise, depth-wise, and width-wise convolution.

The DBGC unit efficiently encodes spatial and dimension wise information using a multi-stage approach. The dimension selector (Ds) module allows flexible dimension choice, and the dimension-wise blend module (DimBlend) refines the process. In local fusion, YDim consolidates outputs from Ds, while DimBlend employs a group point-wise convolution layer (Kg) for dimension-wise merging. Global fusion follows, with DimBlend learning channel-wise and spatial representations, compressing spatial dimensions into channel-wise via fully connected layers. Integrating local and global fusion, DimBlend produces the final output Y, effectively capturing both spatial and dimension-wise information.

## IV. RESULT ANALYSIS

### A. Implementation of DBGC

The integration of the DBGC unit within a CNN architecture involves the utilization of conventional CNN layers. The architecture's depiction is presented in Fig. 15, providing an overview of the overall arrangement.
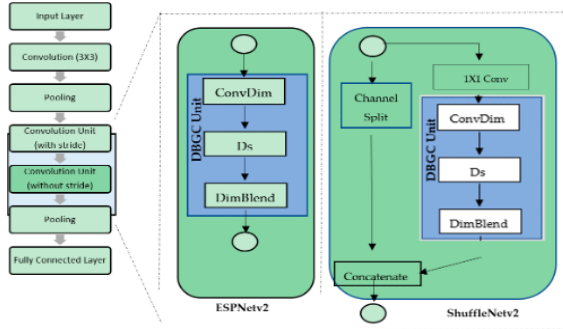


Fig. 15. The DBGC unit in different architecture (ESPNetv2 and ShuffleNetv2) designs.

### B. Experimental Setup

This section provides implementation details of the DBGC block and analyzes results. The DBGC unit was tested on ESPNetv2 and ShuffleNetv2 architectures, evaluating its impact on computational load and accuracy using the PASCAL VOC dataset. The integration of the DBGC unit with different architectures is discussed in Section V.

### C. Dataset Details

To demonstrate the DBGC unit's efficacy across diverse models, a standardized dataset was selected to ensure consistent comparison among architectures. The PASCAL VOC (Visual Object Classes Challenge) dataset was employed for this purpose. This dataset includes 20 object categories such as vehicles, animals, and furniture, with pixel-level segmentation annotations and bounding boxes. It is divided into training, validation, and private testing subsets, serving as a benchmark for object detection, semantic segmentation, and classification tasks.

### D. Results Analysis

This section presents the outcomes of integrating the DBGC unit into ESPNetv2 and ShuffleNetv2 architectures, focusing on the impact of reduced FLOPs on object detection and semantic segmentation accuracy. ESPNetv2 was used for object detection, while ShuffleNetv2 was employed for semantic segmentation. The distinction between FLOPs and FLOPS is explained: FLOPs represents the computational complexity of a model, quantifying the floating-point operations during inference [17]. On the other hand, FLOPS measures hardware processing speed. Faster hardware with higher FLOPS leads to quicker inference times. The equations to calculate FLOPs in the model are detailed in Fig. 16.

Within this section, the analysis of the results is structured into three distinct categories: (1) unoptimized kernel dimensions, (2) semi-optimized kernel dimensions, and (3) optimized kernel dimensions.

| Sr. No | Layer | The Equation to Calculate FLOPs |
|---|---|---|
| 1 | Convolution Layer | 2 × No. of Kernel × Kernel's Shape × Output Shape × Repeat Count (if available) |
| 2 | Pooling Layer (Without stride) | Height × Width × Depth of an input Image |
| 3 | Pooling Layer (With stride) | (Height/Stride) × Depth × (Width/Stride) of an input Image |
| 4 | Fully Connected Layer (FC Layer) | 2 × Input Size × Output Size |

Fig. 16. Output shape of a convolutional layer: Output = (Input - Kernel) + 1.

*1) Unoptimized kernel dimensions*: In the context of unoptimized kernel dimensions, employing a single kernel dimension for the output channel can lead to decreased object detection accuracy. This evaluation used ESPNetv2 and ShuffleNetv2 architectures for object detection and semantic segmentation tasks with the PASCAL VOC dataset. Initial models were created following existing guidelines, and then the same models were integrated with the proposed DBGC block using the width parameter in the dimension selector module from the DBGC architecture. The objective was to observe FLOPs variations and assess Top1 and Top5 accuracies. Results are presented in Tables I, II, and III for width-based, height-based, and depth-based kernels, respectively.

TABLE I. EXCLUSIVELY WIDTH-BASED KERNEL

| Model | Dataset | Image Size | FLOP (In Millions) | Top1 | Top5 |
|---|---|---|---|---|---|
| ESPNet v2 | PASCAL | 224 × 224 | 86 | 66.1 | 70.02 |
| ShuffleNetv2 | | | 71 | 63.9 | 62.30 |
| ESPNetv2(DBGC-KH) | | | 24 | 35.64 | 43.86 |
| ShuffleNetv2 (DBGC-KH) | | | 21 | 34.5 | 39.54 |

TABLE II. SOLELY HEIGHT-BASED KERNEL

| Model | Dataset | Image Size | FLOP (In Millions) | Top1 | Top5 |
|---|---|---|---|---|---|
| ESPNet v2 | PASCAL | 224 × 224 | 86 | 66.1 | 70.02 |
| ShuffleNetv2 | | | 71 | 63.9 | 62.30 |
| ESPNetv2(DBGC-KH) | | | 24 | 33.4 | 37.66 |
| ShuffleNetv2 (DBGC-KH) | | | 21 | 32.15 | 36.84 |

TABLE III. ONLY DEPTH-BASED KERNEL

| Model | Dataset | Image Size | FLOP (In Millions) | Top1 | Top5 |
|---|---|---|---|---|---|
| ESPNet v2 | PASCAL | 224 × 224 | 86 | 66.1 | 70.02 |
| ShuffleNetv2 | | | 71 | 63.9 | 62.30 |
| ESPNetv2(DBGC-KD) | | | 24 | 33.34 | 36.66 |
| ShuffleNetv2 (DBGC-KD) | | | 21 | 31.95 | 35.84 |

The results show that unoptimized kernel dimensions reduce FLOPs by about one third compared to the original ESPNetv2 and ShuffleNetv2 architectures. However, using only a single dimension for kernel selection notably decreases accuracy by around 30%, as demonstrated in Fig. 17 to Fig. 19, highlighting the trade-off between computational efficiency and model performance.
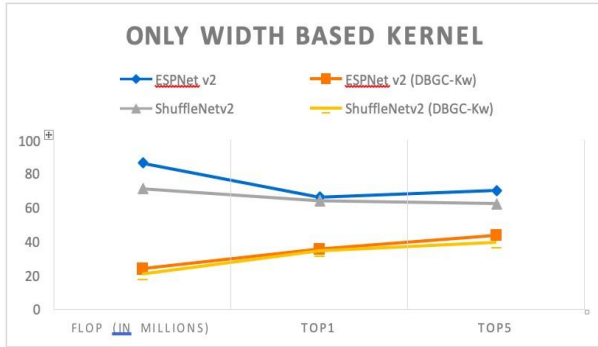


Fig. 17. Only height-based kernel.
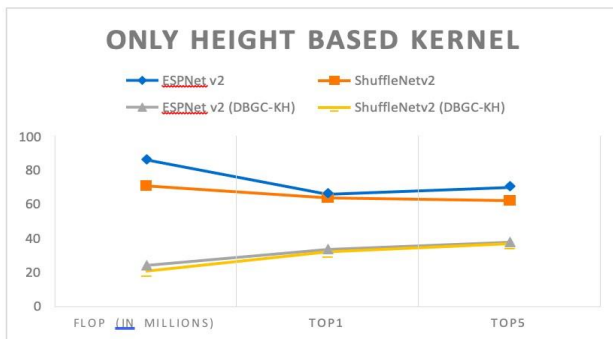


Fig. 18. Only height-based kernel.
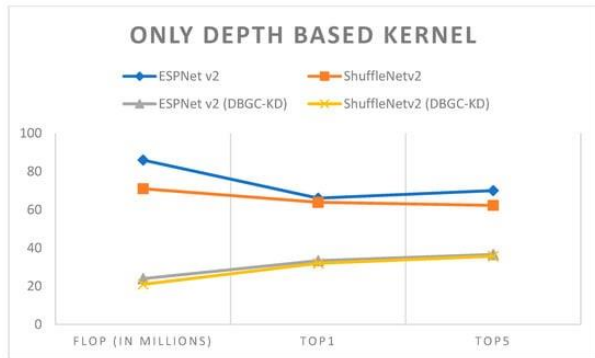


Fig. 19. Only depth-based kernel.

*2) Semi-optimized kernel dimensions*: In the semi-optimized kernel dimensions analysis, two kernel dimension combinations were employed for the output channel, resulting in reduced FLOPs with minimal accuracy loss. ESPNetv2 and ShuffleNetv2 were utilized for object detection and semantic segmentation on the PASCAL VOC dataset. The DBGC block was integrated with various kernel combinations (DBGC-Kwh, DBGC-Kdh, DBGC-Kwd) in dimension selector modules. Results in Tables IV to VI demonstrate lowered FLOPs and slight accuracy effects.

TABLE IV. DEPTH & WIDTH-BASED KERNEL

| Model | Dataset | Image Size | FLOP (In Millions) | Top1 | Top5 |
|---|---|---|---|---|---|
| ESPNet v2 | PASCAL | 224 x 224 | 86 | 70.02 | 66.1 |
| Shuffle Netv2 | | | 71 | 62.30 | 63.9 |
| ESPNetv2(DBGC-KDW) | | | 48 | 71.59 | 66.41 |
| Shuffle Netv2 (DBGC-KDW) | | | 42 | 64.83 | 69.75 |

TABLE V. DEPTH & HEIGHT-BASED KERNEL

| Model | Dataset | Image Size | FLOP (In Millions) | Top1 | Top5 |
|---|---|---|---|---|---|
| ESPNet v2 | PASCAL | 224 x 224 | 86 | 70.02 | 66.1 |
| Shuffle Netv2 | | | 71 | 62.30 | 63.9 |
| ESPNetv2(DBGC-KDH) | | | 48 | 65.57 | 68.42 |
| Shuffle Netv2 (DBGC-KDH) | | | 42 | 65.82 | 67.73 |

TABLE VI. HEIGHT & WIDTH-BASED KERNEL

| Model | Dataset | Image Size | FLOP (In Millions) | Top1 | Top5 |
|---|---|---|---|---|---|
| ESPNet v2 | PASCAL | 224 x 224 | 86 | 70.02 | 66.1 |
| Shuffle Netv2 | | | 71 | 62.30 | 63.9 |
| ESPNetv2(DBGC-KHW) | | | 48 | 65.52 | 71.47 |
| Shuffle Netv2 (DBGC-KHW) | | | 42 | 64.87 | 68.77 |

Semi-optimized kernel dimensions in DBGC halve FLOPs while maintaining good accuracy; object detection sustains accuracy and semantic segmentation gains 1-2%, as shown in Fig. 20 to Fig. 22.
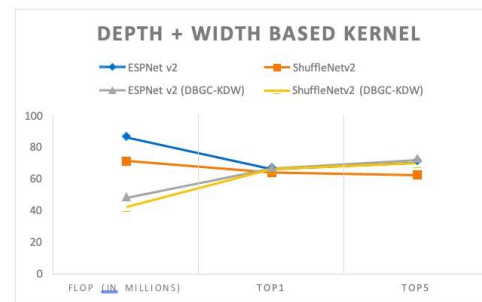


Fig. 20. Combining depth-based and width-based kernels.
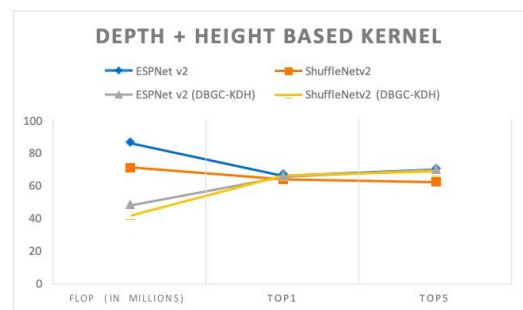


Fig. 21. Combining depth-based and height-based kernel.
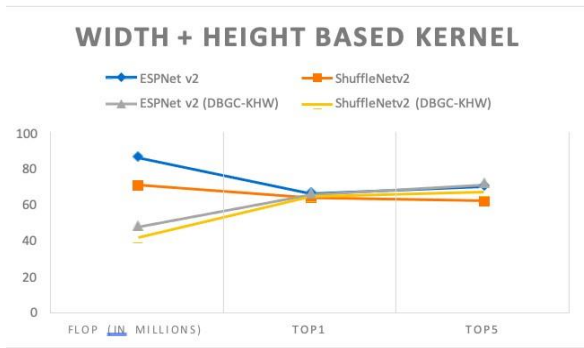
Fig. 22. Combining height-based and width-based kernel.

Fig. 23 illustrates the analysis of results, showing that using two dimensions reduces FLOPs while maintaining accuracy close to the original architecture.
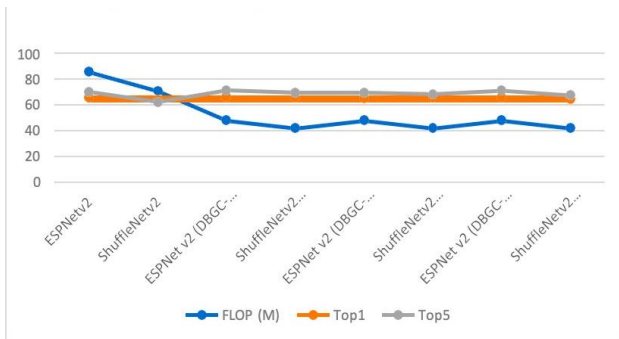


Fig. 23. Semi-optimized kernel dimension.

### E. Optimized Kernel Dimension

To improve accuracy while considering computational efficiency, a combination of all three kernel dimensions (width, height, and depth) was employed for the output channel. This approach increased FLOPs but enhanced accuracy. After implementing ESPNetv2 and ShuffleNetv2 models following the methodology in [7], these models were further enhanced with the incorporation of the proposed DBGC-Khwd block. The DBGC block's parameters for width, height, and depth, as described in Section 3 of the DBGC architecture, were chosen. The goal was to compare FLOPs and evaluate Top1 and Top5 accuracies. The outcomes are presented in Table VII and Fig. 24 for kernels based on depth, width, and height.

TABLE VII. HEIGHT & WIDTH & DEPTH-BASED KERNEL

| Model | Dataset | Image Size | FLOP (In Millions) | Top1 | Top5 |
|---|---|---|---|---|---|
| ESPNet v2 | PASCAL | 224 x 224 | 86 | 70.02 | 66.1 |
| Shuffle Netv2 | | | 71 | 62.30 | 63.9 |
| ESPNetv2(DBGC-KHW) | | | 48 | 70.52 | 74.48 |
| Shuffle Netv2 (DBGC-KHW) | | | 42 | 69.97 | 74.77 |
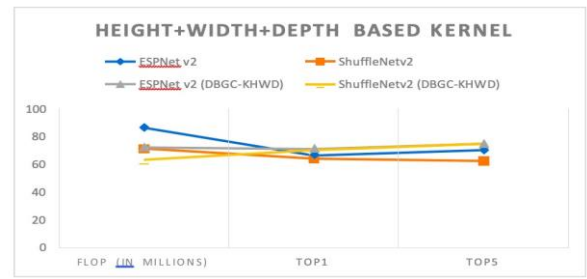


Fig. 24. Optimized kernel dimension.

Fig. 25 highlights that selecting all three dimensions led to a 4 to 5% accuracy increase while reducing FLOPs. showcasing the superiority of optimized kernels. For a comprehensive comparison, Fig. 25 and Fig. 26 display the performance of unoptimized, semi-optimized, and optimized kernel dimensions in ESPNetv2 and ShuffleNetv2 architectures, respectively.
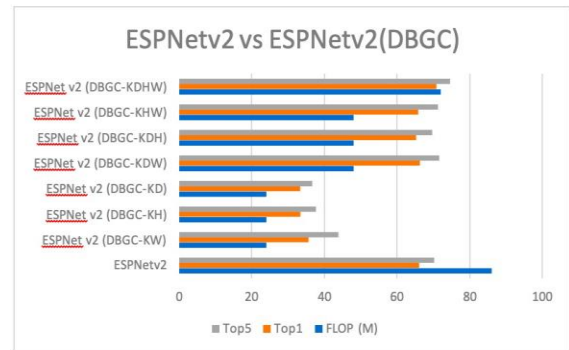


Fig. 25. ESPNetv2 versus ESPNetv2 (DBGC).
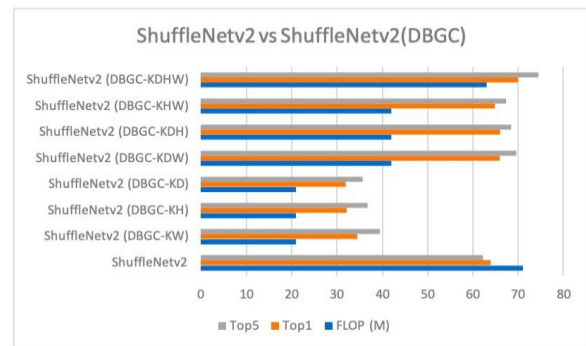


Fig. 26. ShuffleNetv2 versus ShuffleNetv2 (DBGC).

Fig. 27 presents a box plot summarizing the various methods employed on the PASCAL VOC dataset. "Ev2" represents ESPNetv2, and "Sv2" stands for ShuffleNetv2 in the chart.

A box plot visualizes the performance of unoptimized, semi-optimized, and optimized kernels for ESPNetv2 versus ESPNetV2 (DBGC) and ShuffleNetv2 versus ShuffleNetV2 (DBGC). The effectiveness of DBGC is evaluated using the MS COCO dataset [19], showcasing the performance differences in Fig. 28.
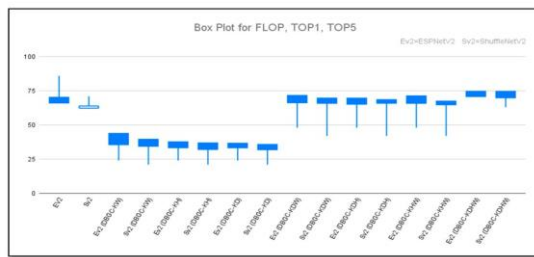
Fig. 27. Box Plot for kernel types.
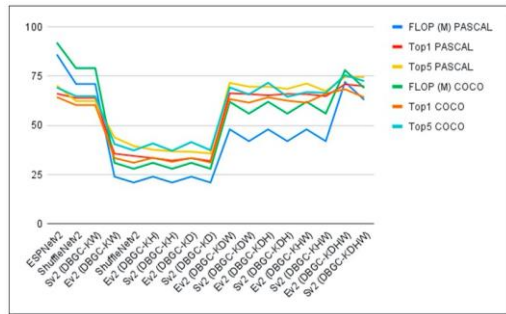


Fig. 28. Compare the performance of ESPNetv2 and ShuffleNetv2 with their DBGC-enhanced versions on PASCAL and COCO datasets.

## V. CONCLUSION

In conclusion, the proposed DBGC unit demonstrates its versatility by being applicable to various CNN-based network models. By integrating DBGC into ESPNetv2 and ShuffleNetv2 architectures, extensive evaluations based on FLOPs, Top1, and Top5 accuracies were conducted using the PASCAL VOC dataset. The findings indicate that unoptimized kernel based DBGC substantially reduces FLOPs by about one third, leading to significantly improved speed. However, this reduction in FLOPs comes at the cost of a notable decrease in accuracy. On the other hand, semi-optimized dimension-based kernels offer a balance between reduced FLOPs (around half) and maintained or slightly improved accuracy in ShuffleNetV2 with DBGC. Lastly, optimized dimension-based kernels achieve the highest accuracy while still reducing FLOPs by approximately five million. These results emphasize the potential of DBGC for enhancing the efficiency and accuracy of various CNN architectures.

## FUTURE WORK

For future research, the proposed architecture could be extended to evaluate its performance across different datasets, enabling a broader understanding of its capabilities. Additionally, investigating whether unoptimized dimension-based kernels can yield improved accuracy when applied to single dimensional data could be a valuable exploration. Further enhancements could involve automating the dimension selection process in the dimension selector modules to dynamically choose dimensions based on the characteristics of the datasets provided, potentially optimizing the efficiency and effectiveness of the DBGC approach.

REFERENCES

[1] Bhatt, D.; Patel, C.; Talsania, H.; Patel, J.; Vaghela, R.; Pandya, S.; Modi, K.; Ghayvat, H. CNN Variants for Computer Vision: History,

[2] Architecture, Application, Challenges and Future Scope. Electronics 2021, 10, 2470. [CrossRef]

[3] Bhatt, D.; Bhensadadiya, N.P. Survey On Various Intelligent Traffic Management Schemes For Emergency Vehicles. Int. J. Recent Innov. 2013, 1, 11–16.

[4] Garg, S.; Patel, C.; Tank, H.; Ukani, V. Efficient Vehicle Detection and Classification for Traffic Surveillance System. In Proceedings of the International Conference on Advances in Computing and Data Sciences, Ghaziabad, India, 11–12 November 2016; pp. 495–503.

[5] Garg, S.; Zaveri, T.; Banerjee, J.; Patel, R.; Patel, C.I. Human action recognition using fusion of features for unconstrained video sequences. Comput. Electric. Eng. 2018, 70, 284–301.

[6] Zhang, X.; Zheng, H.-T.; Sun, J.; Ma, N. ShuffleNet V2: Practical Guidelines for Efficient CNN Architecture Design. In Proceedings of the Computer Vision and Pattern Recognition, Salt Lake City, UT, USA, 18–22 June 2018; Available online: https://arxiv.org/abs/1807.11164v1 (accessed on 20 January 2022).

[7] Rastegari, M.; Shapiro, L.; Hajishirzi, H.; Mehta, S. ESPNetv2: A LightWeight, Power Efficient, and General Purpose Convolutional Neural Network. arXiv 2019, arXiv:1811.11431.

[8] Mehta, S.; Hajishirzi, H.; Rastegari, M. DiCENet: Dimension-wise Convolutions for Efficient Networks. IEEE Trans. Pattern Anal. Mach. Intell. 2020. [CrossRef]

[9] Howard, A.; Zhu, M.; Zhmoginov, A.; Chen, L.-C.; Sandler, M. MobileNetV2: Inverted Residuals and Linear Bottlenecks. In Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition (CVPR), Salt Lake City, UT, USA, 18–23 June 2018; pp. 4510–4520.

[10] Feng, C.; Zhuo, S.; Zhang, X.; Shen, L.; Aleksic, M.; Sheng, T. A Quantization-Friendly Separable Convolution for MobileNets. In Proceedings of the 1stWorkshop on Energy Efficient Machine Learning and Cognitive Computing for Embedded Applications (EMC2),Williamsburg, VA, USA, 25 March 2018; pp. 14–18.

[11] Zhu, F.; Liu, J.; Liu, G.; Zhang, R. Depth-Wise Separable Convolutions and Multi-Level Pooling for an Efficient Spatial CNN-Based Steganalysis. IEEE Trans. Inf. Forensics Secur. 2020, 15, 1138–1150.

[12] Yin, Z.; Wu, M.; Wu, Z.; Kamal, K.C. Depthwise separable convolution architectures for plant disease classification. Comput.Electron. Agric. 2019, 165, 104948.

[13] Choi, Y.; Choi, H.; Yoo, B. Fast Depthwise Separable Convolution for Embedded Systems. In Proceedings of the International Conference on Neural Information Processing (ICONIP), Siem Reap, Cambodia, 13–16 December 2018.

[14] Kaiser, L.; Gomez, A.N.; Chollet, F. Depthwise Separable Convolutions for Neural Machine Translation. arXiv 2017, arXiv:1706.03059.

[15] Tran, M.-K.; Yeung, S.-K.; Hua, B.-S. Pointwise Convolutional Neural Networks. In Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition (CVPR), Salt Lake City, UT, USA, 18–23 June 2018; pp. 984–993.

[16] Bracewell, R. Two-Dimensional Convolution. In Fourier Analysis and Imaging; Springer: Boston, MA, USA, 2003.

[17] Wang, H.; Zhang, Q.; Yoon, S.W.; Won, D.; Lu, H. A 3D Convolutional Neural Network for Volumetric Image Semantic Segmentation. Procedia Manuf. 2019, 39, 422–428.

[18] Gosling, J.B. Floating Point Operation. In Design of Arithmetic Units for Digital Computers; Springer: New York, NY, USA, 1980.

[19] Zhu, M.; Chen, B.; Kalenichenko, D.;Wang,W.; Howard, A.G. Mobilenets:Efficient convolutional neural networks for mobile vision applications. arXiv 2017, arXiv:1704.04861.

[20] MS COCO Dataset. Available online: https://cocodataset.org/#download (accessed on 20 January 2022).

[21] Bosamiya, D.; Kamariya, N.; Miyatra, A. A Survey on Disease and Nutrient Deficiency Detection in Cotton Plant. Int. J. Recent Innov. Trends Comput. Commun. 2013, 1, 812–815.

# HHO-SMOTe: Efficient Sampling Rate for Synthetic Minority Oversampling Technique Based on Harris Hawk Optimization

Khaled SH. Raslan, Almohammady S. Alsharkawy, K. R. Raslan

Department of Mathematics, Faculty of Science, Al-Azhar University, Cairo, Egypt

*Abstract*—Classifying imbalanced datasets presents a significant challenge in the field of machine learning, especially with big data, where instances are unevenly distributed among classes, leading to class imbalance issues that affect classifier performance. Synthetic Minority Over-sampling Technique (SMOTE) is an effective oversampling method that addresses this by generating new instances for the under-represented minority class. However, SMOTE's efficiency relies on the sampling rate for minority class instances, making optimal sampling rates crucial for solving class imbalance. In this paper, we introduce HHO-SMOTe, a novel hybrid approach that combines the Harris Hawk optimization (HHO) search algorithm with SMOTE to enhance classification accuracy by determining optimal sample rates for each dataset. We conducted extensive experiments across diverse datasets to comprehensively evaluate our binary classification model. The results demonstrated our model's exceptional performance, with an AUC score exceeding 0.96, a high G-means score of 0.95 highlighting its robustness, and an outstanding F1-score consistently exceeding 0.99. These findings collectively establish our proposed approach as a formidable contender in the domain of binary classification models.

*Keywords—Imbalanced data; machine learning; over-sampling; SMOTE; HHO*

## I. INTRODUCTION

The applications of Machine Learning (ML) have seen a growing trend in classification domains involving data for automating processes. However, the process of training presents difficulties due to inherent nature of algorithms, which typically learn from datasets with balanced distributions [1]. As a result, acquiring knowledge from datasets with uneven distributions can lead to reduced accuracy and dependability in the resulting model. This phenomenon is termed "imbalance" or "unbalance" [2].

In contemporary applications, addressing challenges posed by imbalanced data has emerged as a notable issue. This issue is particularly evident in various domains such as the detection of fraud telephone calls [3], text classification [4], and biomedical data analysis [5, 6]. The classification of imbalanced data stands as a significant concern within the realms of machine learning and data mining [7]. In the context of imbalanced datasets, a notable discrepancy exists, with one class containing notably fewer training instances (Minority class) than the other (Majority class). In dealing with imbalanced datasets, conventional machine learning and classification algorithms frequently exhibit a tendency to

achieve very high accuracy rates in classifying the majority class, while attaining notably lower accuracy rates when classifying the minority class [8]. Therefore, the classifier's effectiveness suffers when it comes to diagnosing samples from the minority class. Consequently, the classification of imbalanced datasets presents a substantial hurdle in the realm of classification research. Conversely, in numerous practical scenarios, the emphasis is placed on recognizing minority class samples rather than their majority counterparts [9].

In this paper, we emphasize the critical nature of class imbalance and its adverse consequences on the performance of traditional classifiers in real-world applications, such as medical diagnosis, fraud detection, and anomaly detection. To overcome these problem and shortage, we present a unique hybrid binary classification method that integrates multiple algorithms, enhancing the overall robustness of the approach. The core of our methodology lies in the utilization of the Harris Hawk optimization search algorithm, which facilitates the calculation of optimal sample rates for each minority class, resulting in improved representation within the data set. By strategically adapting the SMOTE technique with Harris Hawk Search, we ensure more effective synthetic data generation, tailored to capture the specific characteristics of the imbalance data.

The SMOTE has emerged as a contender for effectively addressing the classification of imbalanced datasets [10]. This technique operates by generating new instances for the under-represented minority class, effectively re-balancing the dataset by augmenting the presence of minority class data points using SMOTE framework. These algorithms adopt a uniform sampling rate for all instances. Unfortunately, this uniform approach leads to suboptimal performance outcomes. This limitation becomes particularly pronounced when the dataset presents varying degrees of difficulty across different instances of the minority class. Instances that are inherently harder to classify may benefit from a different sampling strategy compared to instances that are relatively easier to classify. This nuanced variation is often not accounted for by the uniform sampling rate strategy, resulting in missed opportunities to improve the overall performance of the classification model. As a result, there exists a need for more sophisticated techniques that can deceptively adjust the sampling rates based on the inherent complexities within the minority class instances. By doing so, the resulting classification model could achieve more accurate and refined

outcomes, effectively mitigating the limitations imposed by the current SMOTE-based methodologies.

Within our paper, we propose an innovative algorithm that builds upon the foundation of the SMOTE technique while incorporating the HHO [11] to enhance the efficacy of imbalanced data classification. The integration of the HHO algorithm introduces a dynamic approach wherein diverse sampling rates are generated for individual instances of the minority class. This process culminates in the identification of an optimal combination of these sampling rates. Subsequently, this amalgamation of optimal sampling rates is formulated and seamlessly integrated into the SMOTE Algorithm. The quest for these optimal sampling rates is executed with a high degree of intelligence, ensuring an insightful search process. Once these optimal rates are successfully pinpointed, over-sampling is carried out exclusively on the instances belonging to the minority class, with each instance benefiting from its corresponding optimal sampling rate.

The subsequent sections of this paper are structured as follows: In Section II introducing an overview of current methodologies utilized for handling imbalanced datasets. Section III describes the SMOTE technique and the HHO algorithm in some detail. Section IV delves into the intricacies of our novel HHO-SMOTe algorithm, presenting a detailed account of its design and functionality, Section V guides you through a comprehensive examination of outcomes, encompassing diverse datasets and a variety of algorithms. Section VI concludes this paper.

## II. Related Work

A lot of research papers [2, 12, 13] have create a comprehensive examination of imbalanced datasets. These studies have not only conducted reviews but have also put forth various solutions aimed at effectively addressing the challenge of imbalanced data. Their objective is to determine the most optimal approach that exhibits superior performance in handling this issue. Ebenuwa et al. [12] introduced a feature selection approach for handling imbalanced datasets. They outlined the methodology and implementation steps, evaluating its effectiveness using machine learning algorithms like decision trees, logistic regression, and support vector machines. Their study aimed to identify the algorithm most suitable for addressing imbalanced data challenges through this ensemble of classifiers. The approach proposed in [13] involves the incorporation of an oversampling technique that meticulously incorporates all minority samples during the classification process within the training data. The Study conducted a comprehensive evaluation of this technique by comparing its performance against state-of-the-art ensemble learning methods. The objective behind this assessment was to ascertain the prowess of the oversampling technique in addressing imbalanced data scenarios.

Liu et al. [14] proposed advanced EasyEnsemble and BalanceCascade algorithms to address class imbalance issues more effectively than existing methods. Their research revealed that both algorithms outperformed established techniques, demonstrating their efficiency in tackling class imbalance challenges. Additionally, the authors in [15] devised the GASMOTE algorithm, which introduces a novel approach of employing distinct sampling rates tailored to individual instances within minority classes. This algorithm intelligently identifies the optimal combination of these sampling rates. Empirical evaluations performed on ten prototypical imbalanced datasets unveiled compelling outcomes. When juxtaposed against the SMOTE algorithm, GASMOTE exhibited an impressive enhancement. The empirical results derived from this application validate the GASMOTE algorithm's precision.

Nnamoko and Korkontzelos in [16] have taken strides in the realm of diabetes prediction by devising an optimized iteration of the SMOTE technique. This advanced algorithm integrates the InterQuartile Range technique to strategically oversample dispersed or extreme data prior to the application of SMOTE. This pre-processing step contributes significantly to enhancing the distribution of training samples, ultimately bolstering the efficacy of the diabetes prediction model. Liu st al. [17] brought forth a pioneering contribution in the arena of data balance within the context of spam detection. They proposed a sophisticated algorithm termed Fuzzy-based OverSampling, which revolves around the utilization of fuzzy logic principles to carefully harmonize the data distribution in synthetic sampling endeavors. This innovative methodology exhibited its prowess in not only rectifying the class imbalance but also in fine-tuning the distribution to be more representative of the real-world scenario. Notably, this enhancement manifested in elevated precision levels across a diverse array of ensemble learning models employed for the spam detection task.

The authors in [18] undertook a significant enhancement of the SL-SMOTE technique by incorporating an evolutionary optimization procedure to fine-tune its algorithmic parameters. This evolved rendition, aptly labeled Evolutionary SL-SMOTE, attained exemplary performance metrics when evaluated in the context of seminal quality prediction using AdaBoost. In the research conducted by Susan and Kumar [19], a comprehensive survey was undertaken to delve into the realm of preprocessing techniques within the domain of machine learning applications. The scholarly paper in question provides an in-depth exploration of various sampling methodologies, delving into the intricacies of how each of the scrutinized works tactically incorporated the suggested remedies. The culmination of this survey encompasses a thorough summary of the experimental protocols employed, encompassing intricate procedural insights as well as the comprehensive compilation of the outcomes that were documented.

To address more effectively the issue of how to determine the proper sample rate of the minority instances involved in the synthesis to avoid the generated minority instances decreasing the learning efficiency of the classification process, in this paper, we propose HHO-SMOTe which is also an improved variant of SMOTE based on a novel nature inspired algorithm call HHO. Nevertheless, HHO-SMOTe emphasis on determine the appropriate minority instances which increase the accuracy of the classification algorithmic.

## III. PRELIMINARIES

The SMOTE and exploratory and exploitative stages of the Harris Hawk Optimization algorithm are covered in this section. We explained the different procedures and steps used by each algorithm. In addition, we demonstrate how these various phases have been used to develop a novel algorithm. Due to the integration of the two algorithms, our method can dynamically adapt to a variety of datasets and consistently produce the best results with a high degree of efficiency.

### A. SMOTE

SMOTE is commonly used when dealing with imbalanced datasets, where one class (minority class) has significantly fewer examples than the other class (majority class). In such cases, machine learning models may struggle to correctly classify the minority class because they tend to be biased towards the majority class. SMOTE helps address this imbalance by generating synthetic examples of the minority class to create a more balanced dataset for training.
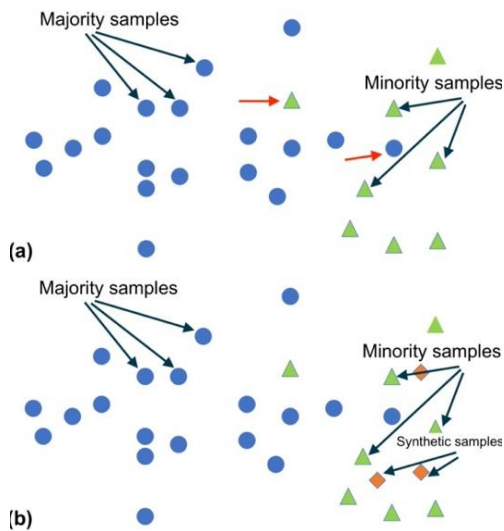


Fig. 1. The principle of the SMOTE.

We can observe an example of an imbalanced dataset in Fig. 1(a) above. Here, the majority class is represented by circular shapes, which stand in for the data's predominant occurrences, while the minority class is represented by triangular shapes, signifying the smaller number of data samples. Some examples from the minority and majority classes are in areas that do not naturally align with the opposite class, most notably with the red arrow. The SMOTE algorithm initiates the process of selecting synthetic samples, a crucial step in bolstering the minority class. The sampling rate specified for each category of occurrences serves as the basis for this selection process. The synthetic samples are presented as square forms in Fig. 1(b). Upon applying the SMOTE technique, the resultant effect is a reduction in the disparity between the Minority and Majority classes.

The SMOTE algorithm includes a sample rate parameter to control the extent of over-sampling. The sample rate determines how many synthetic examples are generated for each minority class instance. Here's an equation that includes the sample rate in the SMOTE algorithm:

$$C = A + s * (B - A) \quad (1)$$

where:
- $C$ is the synthetic example being generated.
- $A$ is a randomly selected instance from the minority class.
- $B$ is one of the k nearest neighbors of $A$ (also from the minority class) and is randomly chosen.
- $s$ is the sample rate parameter, which influences how many synthetic examples are generated between $A$ and $B$. The $s$ parameter is a value between *0* and *1*, which allows you to control the density of synthetic examples to be generated. When $s = 0.5$, one synthetic example is generated exactly. This can be seen as an average or balanced interpolation between the two instances. If $s$ is less than *0.5*, the synthetic examples will be closer to $A$ than $B$, otherwise the synthetic examples will be closer to $B$ than $A$.

Impact of sample rate to balance Dataset:

The choice of s influences how many synthetic instances are generated and how they are distributed between A and B. By adjusting s, you can fine-tune the balance of your dataset. A smaller s may be suitable if you want a moderate increase in the minority class, while a larger s will result in a more substantial over-sampling. As Addressed class imbalance in datasets using the SMOTE algorithm is a common strategy in machine learning, but selecting the appropriate sample rate presents a challenging task. There are no universal guidelines for determining the ideal sample rate, as it hinges on various factors like dataset characteristics, machine learning algorithms, and problem-specific nuances. The primary goal of SMOTE is to balance class distribution, vital for training fair and effective models. However, selecting the wrong sample rate can lead to overfitting, underfitting, or suboptimal model performance.

Researchers in [20-23] often use SMOTE approaches to balance their datasets before staring work on the classification or feature selection, or cluster problems without working with the sample rate selection for the minority classes. Grid search involves trying out a range of predefined sample rates and selecting the one that optimizes evaluation metrics such as precision, recall, F1-score, or AUC. Cross-validation enhances this process by providing a more robust assessment across multiple data subsets. An iterative refinement process, where researchers gradually narrow down the optimal sample rate through experimentation and analysis, is common practice. Additionally, understanding the sensitivity of machine learning algorithms to different sample rates is crucial.

In summary, choosing the right sample rate in SMOTE is a nuanced decision that relies on empirical methods, domain expertise, and iterative exploration to strike the balance that suits the dataset and problem domain. We have put forth our solution for determining the most accurate sample rate, which will be applied when generating samples from the minority classes to achieve data set balance. This solution leverages the intelligence of the HHO algorithm, a sophisticated optimization technique.

## B. Harris Hawks Optimizer (HHO)

The HHO has introduced by Ali Asghar Heidari in 2019, the HHO algorithm has garnered significant attention from the research community [11, 24]. HHO draws inspiration from the hunting behavior of Harris Hawks in nature, particularly their agile surprise pounce technique. Harris Hawks, known for their remarkable intelligence, exhibit various chasing styles based on different scenarios and the behavior of their prey. HHO is widely recognized as one of the most effective optimization algorithms, and it has been successfully applied to a variety of problems across different domains encompass energy and power flow analysis, engineering, medical applications, network optimization, and image processing. The comprehensive review [25-28] presents a survey of the existing body of work related to HHO.

Within this section, shows the modeling of both the exploratory and exploitative phases inherent in HHO methodology. The phases are done by three steps draw inspiration from the natural behaviors of Harris hawks, including their approaches to prey exploration, surprise pouncing, and the diverse attack strategies employed. HHO represents a population-based optimization approach devoid of gradients, rendering it adaptable to a wide array of optimization challenges, provided that they are appropriately formulated. The detailed explanations provided in the subsequent subsections.

*1) Exploration phase*: Hawks perch in specific locations and constantly monitor the surrounding environment to identify prey using two strategies, which are represented in Eq. (2). If $p < 0.5$, the hawks perch based on the position of the family members. If $p \geq 0.5$, the hawks perch in a random space within the population area.

$$X(t + 1) = \begin{cases} X_{rand}(t) - r_1 \mid X_{rand}(t) - 2r_2 X(t) \mid & q \geq 0.5 \\ (X_{rabbit}(t) - X_m(t)) - r_3(LB + r_4(UB - LB)) & q < 0.5 \end{cases} \quad (2)$$

where $X(t + 1)$ is the position vector of hawks in the next iteration $t$, Xrabbit(t) is the position of rabbit, $X(t)$ is the current position vector of hawks, $r_1$, $r_2$, $r_3$, $r_4$, and $q$ are random numbers inside *(0, 1)*, which are updated in each iteration, $LB$ and $UB$ show the upper and lower bounds of variables, $Xrand(t)$ is a randomly selected hawk from the current population, and $X_m$ is the average position of the current population of hawks.

The HHO utilized a simple model to generate random locations inside the group's home range *(LB, UB)*. The first rule generates solutions based on a random location and other hawks. In second rule of Eq. (2), we have the difference of the location of best so far and the average position of the group plus a randomly-scaled component based on range of variables, while $r_3$ is a scaling coefficient to further increase the random nature of rule once $r_4$ takes close values to 1 and similar distribution patterns may occur. Utilizing the simplest rule, which can mimic the behaviors of hawks. The average position of hawks is attained using Eq. (3):

$$X_m(t) = \frac{1}{N} \sum_{i=1}^{N} X_i(t) \quad (3)$$

where, $X_i(t)$ indicates the location of each hawk in iteration $t$ and $N$ denotes the total number of hawks.

*2) Transition from exploration to exploitation*: The HHO can transfer from exploration to exploitation and then, change between different exploitative behaviors based on the escaping energy of the prey. The energy of a prey decreases considerably during the escaping behavior. To model this fact, the energy of a prey is modeled as:

$$E = 2E_0(1 - \frac{t}{T}) \quad (4)$$

Where $E$ indicates the escaping energy of the prey, $T$ is the maximum number of iterations, and $E_0$ is the initial state of its energy. In HHO, $E_0$ randomly changes inside the interval *(−1, 1)* at each iteration. When the value of $E_0$ decreases from *0* to *−1*, the rabbit is physically flagging, whilst when the value of $E_0$ increases from *0* to *1*, it means that the rabbit is strengthening.

*3) Exploitation phase*: Which the hawks attack the targeted prey. Then, however, the prey tries to escape the attack. Based on hawk attacking behavior and escaping prey behavior, four scenarios will be described as below:

*a) Soft Besiege*: When r $\geq$ 0.5 and |E| $\geq$ 0.5, the rabbit still has enough energy and try to escape by some random misleading jumps but finally it cannot. During these attempts, the Harris' hawks encircle it softly to make the rabbit more exhausted and then perform the surprise pounce. This behavior is modeled by the following rules:

$$X(t + 1) = \Delta X(t) - E \mid J X_{rabbit}(t) - X(t) \mid \quad (5)$$

$$\Delta X(t) = X_{rabbit}(t) - X(t) \quad (6)$$

Where $\Delta X(t)$ is the difference between the position vector of the rabbit and the current location in iteration $t$, $r_5$ is a random number inside *(0, 1)*, and $J = 2(1 − r_5)$ represents the random jump strength of the rabbit throughout the escaping procedure. The $J$ value changes randomly in each iteration to simulate the nature of rabbit motions.

*b)* Hard Besiege: When *r $\geq$ 0.5 and |E| <0.5*, the prey is so exhausted, and it has a low escaping energy. In addition, the Harris' hawks hardly encircle the intended prey to finally perform the surprise pounce. In this situation, the current positions are updated using:

$$X(t + 1) = X_{rabbit}(t) - E \mid \Delta X(t) \mid \quad (7)$$

*c) Soft Besiege with Progressive Rapid Dives*: When still |E| $\geq$ 0.5 but r < 0.5, the rabbit has enough energy to successfully escape and still a soft besiege is constructed before the surprise pounce. This procedure is more intelligent than the previous case, the final strategy for updating the positions of hawks in the soft besiege phase can be performed by:

$$X(t + 1) = \begin{cases} Y \text{ if } F(Y) < F(X(t)) \\ Z \text{ if } F(Z) < F(X(t)) \end{cases} \quad (8)$$

where, $Y$ and $Z$ are obtained using Eq.9 and Eq.10. A simple illustration of this step for one hawk. $Y$ is the hawks next move based on the following rule.

$$Y = X_{rabbit}(t) - E \, |JX_{rabbit}(t) - X(t) \quad (9)$$

To mathematically model the escaping patterns of the prey and leapfrog movements (as called in [22]), the levy flight (LF) concept is utilized in the HHO algorithm. In HHO the hawks dive based on the LF-based patterns using the following rule:

$$Z = Y + S \times LF(D) \quad (10)$$

Where $D$ is the dimension of problem and S is a random vector by size $1 \times D$ and $LF$ is the levy flight function, which is calculated as follows.

$$LF(X) = 0.01 \times \frac{u \times \sigma}{|v|^{\frac{1}{\beta}}}, \sigma = \left(\frac{\Gamma(1 + \beta) \times sin(\frac{\pi \beta}{2})}{\Gamma(\frac{1+\beta}{2}) \times \beta \times 2^{\frac{\beta-1}{2}}}\right)^{\frac{1}{\beta}} \quad (11)$$

Where $u, v$ are random values inside $(0, 1)$, $\beta$ is a default constant set to $1.5$.

*d) Hard Besiege with Progressive Rapid Dives*: When $|E| < 0.5$ and $r < 0.5$, the rabbit has not enough energy to escape and a hard besiege is constructed before the surprise pounce to catch and kill the prey. The situation of this step in the prey side is similar to that in the soft besiege, but this time, the hawks try to decrease the distance of their average location with the escaping prey. Therefore, the following rule is performed in hard besiege condition:

$$X(t + 1) = \begin{cases} Y \; if \; F(Y) \, < \, F(X(t)) \\ Z \; if \; F(Z) \, < \, F(X(t)) \end{cases} \quad (12)$$

where $Y$ and $Z$ are obtained using rules in Eq. (13) and Eq. (14).

$$Y = X_{rabbit}(t) - E \, |JX_{rabbit}(t) - X_m(t) \quad (13)$$

$$Z = Y + S \times LF(D) \quad (14)$$

## IV. The Proposed HHO-SMOTE Algorithm

In this section, the proposed HHO-SMOTe approach is proposed for determining the efficient sample rate to be used in the SMOTE technique. The proposed HHO-SMOTe primary goal is to increase the accuracy of classification of the imbalanced datasets. We employed the HHO algorithm to find the optimum solution based on the KNN classification accuracy in order to get the best sampling rate of the synthetic minority class instances.

The proposed HHO-SMOTe initialized by determining its control parameters such as the population size $N$, the number of minority class instances $n$, and the maximum number of iterations. Then, the algorithm starts by generating a population $X$ with the dimension $N \times n$ from the initial solution as an initial phase for the HHO-SMOTe approach. Each solution $x_i \in X$ represents a candidate sample rate for SMOTe and it is assessed by the value of dataset classification accuracy where the best sample rate (solution) has the highest classification accuracy based on KNN algorithm. The solution can be represented with a raw of n values, these values are 0 and the maximum number of samples for each minority class instance. The 0 value in the first position of $x_i$ indicates that the current instance in the minority class have a sample rate 0 and will not be used in the generation of the synthetic data.

Since, if the value is greater than 0, then the current minority class instance will be utilized in the generation of the synthetic data. For example, a solution $x_i$ for generating a synthetic data which have 6 minority class instances can be represented as $x_i$ = [1, 0, 2, 0, 3, 1]. This means that the sample rate to generate the synthetic date is 1 sample of the first minority class instance, 0 sample of the second minority class instance, two samples of the third minority class instance, and so on. The pseudocode of the HHO-SMOTe is showed in Algorithm 1.

---

**Algorithm 1:** Pseudo-code of HHO-SMOTe approach.

**Inputs**:
The population size $N$ and maximum number of iterations $T$
**Outputs**:
The location of rabbit and its fitness value Initialize the random population $X_i$, $i = 1, 2, \ldots, N$
**while** (stopping condition is not met) **do**
    ***Generate a synthetic data based on current sample rate (solution) using SMOTE alg., then calculate the fitness values of hawks using on KNN alg.***
        Set $X_{rabbit}$ as the location of rabbit (**highest accuracy**)
        **for** (each hawk ($X_i$)) **do**
        Update the initial energy $E_0$ and jump strength J→
        $E_0$ = 2rand() - 1, J = 2(1-rand())
        Update the $E$ using Eq. (4)
        if ($|E| \geq 1$) then (**Exploration phase**)
            Update the location vector using Eq. (2)
        if ($|E| < 1$) then (**Exploitation phase**)
            if ($r \geq 0.5$ and $|E| \geq 0.5$) then (**Soft besiege**)
             Update the location vector using Eq. (5)
            else if ($r \geq 0.5$ and $|E| < 0.5$) then (**Hard besiege**)
             Update the location vector using Eq. (7)
            else if ($r < 0.5$ and $|E| \geq 0.5$) then (**Soft besiege with progressive rapid dives**)
             Update the location vector using Eq. (8)
            else if ($r < 0.5$ and $|E| < 0.5$) then (**Hard besiege with progressive rapid dives**)
             Update the location vector using Eq. (12)
Return Xrabbit

---

### A. Performance Evaluation Measures

Performance evaluation metrics are critical for evaluating classification performance and guiding classifier design. In this step, the confusion matrix was used to get the results of the proposed HHO-SMOTe approach and to make the comparison between all the used SMOTE approaches. The confusion matrix Fig. 2 describes the performance of the classification models. True positive (TP): Observation is predicted positive and is actually positive. False positive (FP): Observation is predicted positive and is actually negative. True negative (TN): Observation is predicted negative and is actually negative. False negative (FN): Observation is predicted negative and is actually positive. From the confusion matrix, we can conclude the following measures:

Actual class

Fig. 2.   Confusion matrix for the two-class classification problem.

*1) G-mean:* The geometric mean is the root of the product of class-wise sensitivity. This measure tries to maximize the accuracy on each of the classes while keeping these accuracies balanced. For binary classification G-mean is the squared root of the product of the sensitivity and specificity. For multi-class problems it is a higher root of the product of sensitivity for each class.

$$G-mean = \sqrt{Sensitivity \times Specificity} \qquad (15)$$

*2) F1 score:* The *F*1 score, *F* score, or *F* measure is the harmonic mean of precision and sensitivity it gives importance to both factors:

$$F1 = \frac{2*Precision*Recall}{Precision+Recall} = \frac{2*TP}{2*TP+FP+FN} \qquad (16)$$

*3) AUC:* The receiver operating characteristics (ROC) curve is the plot between sensitivity and the FP rate for various threshold values. The area under curve (AUC) is the area under this ROC curve; it is used to measure the quality of a classification model. The larger the area, the better the performance. The ROC curve is a two-dimensional coordinate graph in which the X-axis represents the false positive rate (FPR) and Y-axis represent the true positive rate (TPR). The AUC can be calculated as:

$$AUC = \frac{1+TPR-FPR}{2} \qquad (17)$$

## V.   EXPERIMENTS AND EVALUATION

In this section, the experiments were done on different datasets. The following subsections will demonstrate the results and analyze these results. The experiments were conducted on Google Colaboratory, which provides a free Jupyter notebook environment with GPU support for running machine learning experiments [29].

TABLE I.       SUMMARY DESCRIPTION OF IMBALANCED DATASETS

| Dataset | #Att. | Org dataset | #Min. | #Maj. | IR |
|---|---|---|---|---|---|
| abalone9-18 | 8 | 731 | 42 | 689 | 16.40 |
| ada | 47 | 4147 | 1029 | 3118 | 3.03 |
| cleveland-0 | 14 | 177 | 13 | 164 | 12.62 |
| ecoli2 | 7 | 336 | 52 | 284 | 5.46 |
| ecoli3 | 7 | 336 | 35 | 301 | 8.60 |
| ecoli4 | 7 | 336 | 20 | 316 | 15.80 |
| german | 29 | 1000 | 300 | 700 | 2.33 |
| glass0 | 9 | 214 | 70 | 144 | 2.06 |
| glass1 | 9 | 214 | 76 | 138 | 1.82 |
| glass2 | 9 | 214 | 17 | 197 | 11.59 |
| habarman | 3 | 306 | 81 | 225 | 2.78 |
| hypothyroid | 25 | 3163 | 151 | 3012 | 19.95 |
| kc1 | 20 | 2109 | 326 | 1783 | 5.47 |
| new-thyroid1 | 5 | 215 | 35 | 180 | 5.14 |
| page-blocks0 | 10 | 5472 | 559 | 4913 | 8.79 |
| pc1 | 21 | 1109 | 77 | 1032 | 13.40 |
| Pima | 8 | 768 | 268 | 500 | 1.87 |
| vehicle0 | 18 | 846 | 199 | 647 | 3.25 |
| vehicle1 | 18 | 846 | 217 | 629 | 2.90 |
| vehicle2 | 18 | 846 | 218 | 628 | 2.88 |
| vehicle3 | 18 | 846 | 212 | 634 | 2.99 |
| yeast3 | 10 | 1484 | 163 | 1321 | 8.10 |
| yeast4 | 10 | 1484 | 51 | 1433 | 28.10 |
| yeast5 | 10 | 1484 | 44 | 1440 | 32.73 |
| yeast6 | 10 | 1484 | 35 | 1449 | 41.40 |

In our research, we utilized over 25 diverse datasets in different industries and attributes to evaluate the proposed technique. We maintained the original class distribution with five-fold cross-validation and conducted each experiment five times to obtain average metrics. Table I summarizes dataset details, including the dataset name, the number of attributes, the number of samples for the minority class, the original dataset record numbers, the number of samples in the majority class, and the corresponding imbalance ratio.

Table II presents the outcomes of our experimentation of 19 SMOTe variants approach and the proposed HHO-SMOTe approach with KNN algorithm as the application of SMOTE techniques for oversampling the dataset.The 19 methods are ADASYN [30], AND-SMOTE [31], ANS [32], Borderline-SMOTE1 [33], Borderline-SMOTE2 [33], distance-SMOTE [34], G-SMOTE [35], GASMOTE [15] , Gaussian-SMOTE [36], KernelADASYN [37], kmeans-SMOTE [38], Random-SMOTE [39], Safe-Level-SMOTE [40], SDSMOTE [41], SMOTE [10], SOMO [42], SVM-balance[43], SYMPROD [44], ASN-SMOTE [45]. Notably, we have highlighted in bold the distinctive optimal values achieved for the average G-mean, F1-score, and AUC within the KNN results. This highlighting underscores the noteworthy observation that the combination of HHO-SMOTe consistently yields optimal results across a diverse array of datasets. The classification performance comparison results for the selected seven approaches applied on twelve datasets presented in Fig. 3, 4, and 5 are obtained using data from Table II.

TABLE II. RESULTS OBTAINED BY KNN ON DATASETS OVERSAMPLED BY DIFFERENT SMOTE TECHNIQUES

| Dataset | abalone9-18 | | | ada | | | cleveland-0 | | | ecoli2 | | | ecoli3 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Method | Gmean | F1-score | AUC | Gmean | F1-score | AUC | Gmean | F1-score | AUC | Gmean | F1-score | AUC | Gmean | F1-score | AUC |
| ADASYN | 0.952 | 0.952 | 0.952 | 0.857 | 0.857 | 0.857 | 0.888 | 0.888 | 0.894 | 0.948 | 0.949 | 0.949 | 0.993 | **0.994** | 0.993 |
| AND-SMOTE | 0.969 | 0.969 | 0.969 | 0.866 | 0.866 | 0.866 | 0.95 | 0.949 | 0.95 | 0.931 | 0.93 | 0.932 | 0.988 | 0.988 | 0.988 |
| ANS | 0.961 | 0.961 | 0.961 | 0.856 | 0.856 | 0.856 | 0.979 | 0.981 | 0.982 | 0.923 | 0.923 | 0.923 | 0.971 | 0.971 | 0.971 |
| Borderline-SMOTE1 | 0.972 | 0.975 | 0.975 | 0.864 | 0.864 | 0.864 | 0.969 | 0.97 | 0.969 | 0.967 | 0.968 | 0.967 | **0.996** | 0.994 | **0.995** |
| Borderline-SMOTE2 | 0.963 | 0.964 | 0.963 | 0.874 | 0.874 | 0.874 | 0.928 | 0.929 | 0.93 | 0.968 | 0.968 | 0.968 | 0.989 | 0.988 | 0.989 |
| distance-SMOTE | 0.974 | 0.973 | 0.974 | 0.858 | 0.858 | 0.858 | 0.96 | 0.96 | 0.961 | 0.953 | 0.955 | 0.954 | 0.989 | 0.988 | 0.989 |
| G-SMOTE | 0.961 | 0.961 | 0.961 | 0.857 | 0.857 | 0.857 | 0.963 | 0.96 | 0.964 | 0.941 | 0.942 | 0.941 | 0.989 | 0.987 | 0.991 |
| GASMOTE | 0.634 | 0.650 | 0.668 | 0.503 | 0.446 | 0.507 | 0.850 | 0.845 | 0.851 | 0.900 | 0.894 | 0.900 | 0.494 | 0.375 | 0.510 |
| Gaussian-SMOTE | 0.91 | 0.912 | 0.914 | 0.716 | 0.722 | 0.73 | 0.96 | 0.96 | 0.96 | 0.926 | 0.929 | 0.927 | 0.983 | 0.982 | 0.983 |
| KernelADASYN | 0.954 | 0.954 | 0.955 | 0.856 | 0.857 | 0.857 | 0.972 | 0.97 | 0.973 | 0.975 | 0.974 | 0.975 | 0.976 | 0.977 | 0.976 |
| kmeans-SMOTE | 0.447 | 0.928 | 0.6 | 0.863 | 0.863 | 0.863 | 0.816 | 0.98 | 0.833 | 0.943 | 0.942 | 0.943 | 0.988 | 0.988 | 0.988 |
| Random-SMOTE | 0.948 | 0.947 | 0.948 | 0.854 | 0.854 | 0.854 | 0.939 | 0.939 | 0.941 | 0.955 | 0.955 | 0.955 | 0.982 | 0.982 | 0.982 |
| Safe-Level-SMOTE | 0.954 | 0.954 | 0.954 | 0.804 | 0.804 | 0.804 | 0.861 | 0.858 | 0.864 | 0.962 | 0.962 | 0.962 | 0.983 | 0.982 | 0.983 |
| SDSMOTE | 0.957 | 0.957 | 0.957 | 0.85 | 0.85 | 0.85 | 0.928 | 0.92 | 0.931 | 0.927 | 0.929 | 0.928 | 0.969 | 0.971 | 0.969 |
| SMOTE | **0.976** | **0.976** | **0.976** | 0.848 | 0.848 | 0.848 | 0.931 | 0.939 | 0.933 | 0.955 | 0.955 | 0.955 | 0.983 | 0.982 | 0.983 |
| SOMO | 0.258 | 0.91 | 0.533 | 0.699 | 0.811 | 0.72 | 0.707 | 0.957 | 0.75 | 0.893 | 0.94 | 0.896 | 0.955 | 0.971 | 0.955 |
| SVM-balance | 0.955 | 0.954 | 0.955 | 0.921 | 0.921 | 0.921 | 0.968 | 0.97 | 0.968 | 0.96 | 0.961 | 0.96 | 0.983 | 0.982 | 0.983 |
| SYMPROD | 0.973 | 0.973 | 0.973 | 0.853 | 0.852 | 0.853 | 0.707 | 0.978 | 0.75 | 0.944 | 0.942 | 0.944 | 0.988 | 0.988 | 0.988 |
| ASN-SMOTE | 0.717 | 0.46857 | 0.749 | 0.4782 | 0.20965 | 0.562 | 0.48 | 0.439 | 0.595 | 0.9128 | 0.79798 | 0.914 | 0.8965 | 0.62918 | 0.899 |
| **HHO-SMOTe** | 0.93833 | 0.93533 | 0.94 | **0.941** | **0.934** | **0.935** | **0.981** | **0.99** | **0.989** | **0.987** | **0.983** | **0.985** | 0.982 | 0.982 | 0.982 |

| Dataset | ecoli4 | | | german | | | glass0 | | | glass1 | | | glass2 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Method | Gmean | F1-score | AUC | Gmean | F1-score | AUC | Gmean | F1-score | AUC | Gmean | F1-score | AUC | Gmean | F1-score | AUC |
| ADASYN | 0.938 | 0.939 | 0.938 | 0.791 | 0.794 | 0.794 | 0.883 | 0.885 | 0.886 | 0.866 | 0.878 | 0.87 | 0.938 | 0.941 | 0.939 |
| AND-SMOTE | 0.961 | 0.961 | 0.961 | 0.803 | 0.804 | 0.809 | 0.943 | 0.943 | 0.943 | 0.844 | 0.843 | 0.844 | 0.916 | 0.916 | 0.916 |
| ANS | 0.938 | 0.939 | 0.938 | 0.799 | 0.8 | 0.8 | 0.931 | 0.931 | 0.931 | **0.942** | **0.939** | **0.943** | 0.967 | 0.966 | 0.967 |
| Borderline-SMOTE1 | 0.961 | 0.961 | 0.961 | 0.793 | 0.793 | 0.793 | 0.932 | 0.931 | 0.932 | 0.85 | 0.855 | 0.851 | 0.908 | 0.908 | 0.909 |
| Borderline-SMOTE2 | 0.961 | 0.961 | 0.961 | 0.781 | 0.781 | 0.781 | 0.936 | 0.931 | 0.937 | 0.859 | 0.856 | 0.859 | 0.966 | 0.965 | 0.966 |
| distance-SMOTE | 0.956 | 0.956 | 0.956 | 0.776 | 0.778 | 0.778 | 0.953 | 0.954 | 0.953 | 0.819 | 0.819 | 0.819 | 0.919 | 0.916 | 0.919 |
| G-SMOTE | 0.956 | 0.956 | 0.956 | 0.793 | 0.793 | 0.793 | 0.932 | 0.931 | 0.932 | 0.834 | 0.833 | 0.834 | 0.941 | 0.941 | 0.941 |
| GASMOTE | 0.790 | 0.785 | 0.811 | 0.547 | 0.527 | 0.555 | 0.852 | 0.865 | 0.855 | 0.796 | 0.793 | 0.800 | 0.515 | 0.458 | 0.568 |
| Gaussian-SMOTE | 0.93 | 0.928 | 0.931 | 0.688 | 0.701 | 0.716 | 0.886 | 0.885 | 0.887 | 0.814 | 0.818 | 0.817 | 0.786 | 0.793 | 0.806 |
| KernelADASYN | 0.944 | 0.945 | 0.945 | 0.45 | 0.626 | 0.531 | 0.892 | 0.886 | 0.894 | 0.905 | 0.904 | 0.905 | 0.874 | 0.874 | 0.874 |
| kmeans-SMOTE | 0.956 | 0.956 | 0.95 | 0.796 | 0.797 | 0.79 | 0.96 | 0.961 | 0.96 | 0.929 | 0.928 | 0.92 | 0.401 | 0.87 | 0.56 |

| Method | | | 6 | | | 7 | | | 3 | | | 9 | | 6 | 6 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Random-SMOTE | 0.945 | 0.945 | 0.946 | 0.789 | 0.79 | 0.789 | 0.915 | 0.919 | 0.915 | 0.833 | 0.831 | 0.834 | 0.924 | 0.924 | 0.924 |
| Safe-Level-SMOTE | 0.927 | 0.928 | 0.927 | 0.688 | 0.688 | 0.688 | **0.966** | **0.966** | **0.966** | 0.83 | 0.831 | 0.83 | 0.958 | 0.958 | 0.958 |
| SDSMOTE | 0.966 | 0.966 | 0.966 | 0.792 | 0.792 | 0.795 | 0.92 | 0.919 | 0.921 | 0.853 | 0.855 | 0.853 | 0.95 | 0.95 | 0.952 |
| SMOTE | 0.927 | 0.928 | 0.928 | 0.769 | 0.769 | 0.769 | 0.909 | 0.908 | 0.91 | 0.806 | 0.807 | 0.806 | 0.95 | 0.95 | 0.95 |
| SOMO | 0.823 | 0.941 | 0.834 | 0.502 | 0.668 | 0.596 | 0.935 | 0.938 | 0.935 | 0.782 | 0.799 | 0.785 | 0 | 0.886 | 0.5 |
| SVM-balance | 0.957 | 0.956 | 0.957 | 0.825 | 0.822 | 0.827 | 0.917 | 0.919 | 0.919 | 0.889 | 0.903 | 0.891 | 0.922 | 0.924 | 0.923 |
| SYMPROD | **0.967** | **0.967** | **0.967** | 0.48 | 0.67 | 0.575 | 0.95 | 0.954 | 0.95 | 0.909 | 0.908 | 0.91 | 0 | 0.834 | 0.491 |
| ASN-SMOTE | 0.931 | 0.934 | 0.938 | 0.6485 | 0.47041 | 0.682 | 0.5402 | 0.42331 | 0.53 | 0.2924 | 0.345 | 0.574 | 0.2924 | 0.23 | 0.574 |
| **HHO-SMOTe** | 0.956 | 0.956 | 0.956 | **0.889** | **0.897** | **0.889** | 0.959 | 0.956 | 0.951 | 0.851 | 0.853 | 0.854 | **0.977** | **0.974** | **0.973** |

| Dataset | habarman | | | hypothyroid | | | kc1 | | | new-thyroid1 | | | page-blocks0 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Method | Gmean | F1-score | AUC | Gmean | F1-score | AUC | Gmean | F1-score | AUC | Gmean | F1-score | AUC | Gmean | F1-score | AUC |
| ADASYN | 0.807 | 0.807 | 0.807 | 0.976 | 0.976 | 0.976 | 0.921 | 0.921 | 0.921 | 0.991 | 0.991 | 0.991 | 0.978 | 0.978 | 0.978 |
| AND-SMOTE | 0.754 | 0.755 | 0.757 | 0.977 | 0.977 | 0.977 | 0.945 | 0.945 | 0.945 | 0.963 | 0.963 | 0.963 | 0.983 | 0.983 | 0.983 |
| ANS | 0.79 | 0.791 | 0.794 | 0.976 | 0.976 | 0.976 | 0.915 | 0.916 | 0.916 | 0.674 | 0.893 | 0.727 | 0.979 | 0.979 | 0.979 |
| Borderline-SMOTE1 | 0.778 | 0.778 | 0.778 | 0.981 | 0.981 | 0.981 | 0.926 | 0.926 | 0.926 | 0.991 | 0.991 | 0.991 | **0.984** | **0.984** | **0.984** |
| Borderline-SMOTE2 | 0.765 | 0.763 | 0.766 | 0.975 | 0.975 | 0.975 | 0.917 | 0.917 | 0.917 | 0.981 | 0.981 | 0.981 | 0.978 | 0.978 | 0.978 |
| distance-SMOTE | 0.782 | 0.785 | 0.784 | 0.978 | 0.978 | 0.978 | 0.937 | 0.937 | 0.937 | 0.954 | 0.954 | 0.954 | 0.982 | 0.982 | 0.982 |
| G-SMOTE | 0.781 | 0.778 | 0.781 | 0.975 | 0.975 | 0.975 | 0.941 | 0.941 | 0.941 | 0.991 | 0.991 | 0.991 | 0.978 | 0.978 | 0.978 |
| GASMOTE | 0.487 | 0.445 | 0.495 | 0.863 | 0.844 | 0.871 | 0.827 | 0.817 | 0.827 | 0.744 | 0.717 | 0.745 | 0.627 | 0.597 | 0.68 |
| Gaussian-SMOTE | 0.777 | 0.777 | 0.783 | 0.75 | 0.773 | 0.78 | 0.776 | 0.79 | 0.792 | 0.95 | 0.953 | 0.951 | 0.971 | 0.971 | 0.971 |
| KernelADASYN | 0.794 | 0.792 | 0.801 | 0.987 | 0.987 | 0.987 | 0.968 | 0.981 | 0.968 | 0.972 | 0.972 | 0.972 | 0.975 | 0.975 | 0.975 |
| kmeans-SMOTE | 0.787 | 0.797 | 0.794 | 0.768 | 0.972 | 0.793 | 0.967 | 0.967 | 0.967 | 0.953 | 0.954 | 0.955 | 0.981 | 0.981 | 0.981 |
| Random-SMOTE | 0.787 | 0.791 | 0.79 | 0.979 | 0.979 | 0.979 | 0.922 | 0.922 | 0.923 | 0.99 | 0.991 | 0.99 | 0.977 | 0.977 | 0.977 |
| Safe-Level-SMOTE | 0.807 | 0.814 | 0.809 | 0.957 | 0.957 | 0.957 | 0.922 | 0.922 | 0.922 | 0.972 | 0.972 | 0.973 | 0.978 | 0.978 | 0.978 |
| SDSMOTE | 0.794 | 0.799 | 0.797 | 0.975 | 0.975 | 0.975 | 0.933 | 0.933 | 0.933 | 0.984 | 0.98 | 0.988 | 0.979 | 0.979 | 0.979 |
| SMOTE | 0.764 | 0.763 | 0.766 | 0.979 | 0.979 | 0.979 | 0.942 | 0.943 | 0.942 | 0.991 | 0.991 | 0.991 | 0.982 | 0.982 | 0.982 |
| SOMO | 0.441 | 0.652 | 0.56 | 0.656 | 0.965 | 0.714 | 0.957 | 0.957 | 0.957 | 0.905 | 0.968 | 0.909 | 0.98 | 0.98 | 0.98 |
| SVM-balance | 0.932 | 0.933 | 0.932 | 0.972 | 0.972 | 0.972 | 0.952 | 0.951 | 0.952 | 0.983 | 0.982 | 0.983 | 0.983 | 0.983 | 0.983 |
| SYMPROD | 0.78 | 0.785 | 0.781 | 0.978 | 0.979 | 0.979 | 0.933 | 0.933 | 0.933 | 0.962 | 0.963 | 0.962 | 0.982 | 0.982 | 0.982 |
| ASN-SMOTE | **0.997** | **0.994** | **0.992** | 0.6809 | 0.45673 | 0.696 | 0.68007 | 0.45604 | 0.696 | 0.5894 | 0.34384 | 0.662 | 0.700 | 0.618 | 0.707 |
| **HHO-SMOTe** | 0.7873 | 0.791 | 0.793 | **0.989** | **0.98833** | **0.989** | **0.9806** | **0.98287** | **0.981** | **0.998** | **0.99733** | **0.998** | 0.973 | 0.973 | 0.973 |

| Dataset | pc1 | | | pima | | | vehicle0 | | | vehicle1 | | | vehicle2 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Method | Gmean | F1-score | AUC | Gmean | F1-score | AUC | Gmean | F1-score | AUC | Gmean | F1-score | AUC | Gmean | F1-score | AUC |
| ADASYN | 0.958 | 0.958 | 0.958 | 0.781 | 0.78 | 0.781 | 0.939 | 0.938 | 0.939 | 0.84 | 0.841 | 0.841 | 0.962 | 0.963 | 0.962 |
| AND-SMOTE | 0.965 | 0.965 | 0.965 | 0.783 | 0.783 | 0.783 | 0.949 | 0.949 | 0.949 | 0.833 | 0.833 | 0.833 | 0.969 | 0.968 | 0.969 |

| Method | Gmean | F1-score | AUC | Gmean | F1-score | AUC | Gmean | F1-score | AUC | Gmean | F1-score | AUC | Gmean | F1-score | AUC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ANS | 0.944 | 0.944 | 0.944 | 0.808 | 0.807 | 0.809 | 0.971 | 0.972 | 0.971 | 0.817 | 0.821 | 0.822 | 0.952 | 0.952 | 0.952 |
| Borderline-SMOTE1 | 0.968 | 0.968 | 0.968 | 0.769 | 0.77 | 0.769 | 0.932 | 0.933 | 0.933 | 0.846 | 0.846 | 0.846 | 0.972 | 0.973 | 0.972 |
| Borderline-SMOTE2 | 0.961 | 0.961 | 0.961 | 0.788 | 0.79 | 0.788 | 0.951 | 0.951 | 0.952 | 0.817 | 0.82 | 0.818 | 0.959 | 0.96 | 0.959 |
| distance-SMOTE | 0.972 | 0.973 | 0.972 | 0.809 | 0.81 | 0.81 | 0.955 | 0.954 | 0.955 | 0.858 | 0.86 | 0.859 | 0.946 | 0.944 | 0.947 |
| G-SMOTE | 0.979 | 0.979 | 0.979 | 0.794 | 0.793 | 0.795 | 0.948 | 0.949 | 0.948 | 0.828 | 0.83 | 0.83 | 0.974 | 0.973 | 0.974 |
| GASMOTE | 0.680 | 0.791 | 0.690 | 0.529 | 0.544 | 0.547 | 0.669 | 0.629 | 0.670 | 0.519 | 0.466 | 0.522 | 0.586 | 0.543 | 0.588 |
| Gaussian-SMOTE | 0.821 | 0.834 | 0.835 | 0.723 | 0.741 | 0.729 | 0.866 | 0.866 | 0.872 | 0.697 | 0.711 | 0.717 | 0.883 | 0.885 | 0.888 |
| KernelADASYN | 0.746 | 0.957 | 0.777 | 0.8 | 0.8 | 0.8 | 0.928 | 0.928 | 0.928 | 0.787 | 0.791 | 0.788 | 0.96 | 0.96 | 0.96 |
| kmeans-SMOTE | 0.965 | 0.965 | 0.965 | 0.79 | 0.79 | 0.79 | 0.946 | 0.946 | 0.946 | 0.833 | 0.833 | 0.833 | 0.964 | 0.963 | 0.964 |
| Random-SMOTE | 0.956 | 0.956 | 0.956 | 0.743 | 0.743 | 0.743 | 0.959 | 0.959 | 0.959 | 0.847 | 0.847 | 0.848 | 0.973 | 0.973 | 0.974 |
| Safe-Level-SMOTE | 0.935 | 0.935 | 0.936 | 0.77 | 0.77 | 0.77 | 0.967 | 0.969 | 0.967 | 0.819 | 0.818 | 0.82 | 0.968 | 0.968 | 0.969 |
| SDSMOTE | 0.96 | 0.96 | 0.96 | 0.761 | 0.763 | 0.761 | 0.941 | 0.941 | 0.941 | 0.849 | 0.847 | 0.85 | 0.966 | 0.966 | 0.966 |
| SMOTE | 0.974 | 0.974 | 0.974 | 0.764 | 0.764 | 0.764 | 0.948 | 0.951 | 0.948 | 0.828 | 0.828 | 0.828 | 0.963 | 0.963 | 0.963 |
| SOMO | 0.733 | 0.951 | 0.764 | 0.814 | 0.81 | 0.818 | 0.902 | 0.93 | 0.903 | 0.592 | 0.724 | 0.644 | 0.915 | 0.941 | 0.916 |
| SVM-balance | 0.937 | 0.939 | 0.937 | 0.842 | 0.843 | 0.843 | 0.959 | 0.959 | 0.959 | 0.863 | 0.867 | **0.863** | 0.981 | 0.981 | 0.981 |
| SYMPROD | 0.973 | 0.973 | 0.973 | 0.755 | 0.754 | 0.755 | 0.952 | 0.951 | 0.953 | 0.827 | 0.828 | 0.827 | 0.975 | 0.976 | 0.976 |
| ASN-SMOTE | 0.825 | 0.55594 | 0.838 | **0.983** | **0.957** | **0.984** | 0.793 | 0.625 | 0.815 | 0.6642 | 0.505 | 0.666 | 0.7895 | 0.64697 | 0.799 |
| **HHO-SMOTe** | **0.982** | **0.985** | **0.986** | 0.772 | 0.774 | 0.777 | **0.986** | **0.992** | **0.987** | **0.8637** | **0.89833** | 0.847 | **0.9863** | **0.98767** | **0.988** |

| Dataset | vehicle3 | | | yeast3 | | | yeast4 | | | yeast5 | | | yeast6 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Method | Gmean | F1-score | AUC | Gmean | F1-score | AUC | Gmean | F1-score | AUC | Gmean | F1-score | AUC | Gmean | F1-score | AUC |
| ADASYN | 0.856 | 0.856 | 0.856 | 0.794 | 0.794 | 0.795 | 0.974 | 0.974 | 0.974 | 0.974 | 0.974 | 0.974 | 0.991 | 0.991 | 0.991 |
| AND-SMOTE | 0.863 | 0.864 | 0.863 | 0.794 | 0.795 | 0.794 | 0.976 | 0.976 | 0.976 | 0.981 | 0.981 | 0.981 | 0.988 | 0.987 | 0.988 |
| ANS | 0.865 | 0.866 | 0.866 | 0.822 | 0.822 | 0.822 | 0.975 | 0.975 | 0.975 | 0.975 | 0.974 | 0.975 | 0.66 | 0.972 | 0.716 |
| Borderline-SMOTE1 | 0.873 | 0.874 | 0.874 | 0.826 | 0.826 | 0.826 | 0.974 | 0.974 | 0.974 | 0.984 | 0.984 | 0.984 | 0.99 | 0.99 | 0.99 |
| Borderline-SMOTE2 | 0.859 | 0.858 | 0.86 | 0.828 | 0.829 | 0.829 | 0.958 | 0.958 | 0.958 | **0.986** | **0.986** | **0.986** | 0.987 | 0.987 | 0.987 |
| distance-SMOTE | 0.844 | 0.847 | 0.845 | 0.811 | 0.811 | 0.812 | 0.975 | 0.975 | 0.975 | 0.976 | 0.977 | 0.976 | 0.987 | 0.987 | 0.987 |
| G-SMOTE | 0.845 | 0.845 | 0.845 | 0.805 | 0.804 | 0.805 | 0.972 | 0.971 | 0.972 | 0.977 | 0.977 | 0.977 | 0.987 | 0.987 | 0.987 |
| GASMOTE | 0.527 | 0.476 | 0.530 | 0.464 | 0.318 | 0.479 | 0.498 | 0.522 | 0.566 | 0.476 | 0.481 | 0.555 | 0.408 | 0.407 | 0.520 |
| Gaussian-SMOTE | 0.629 | 0.648 | 0.658 | 0.789 | 0.79 | 0.793 | 0.946 | 0.947 | 0.947 | 0.945 | 0.946 | 0.946 | 0.976 | 0.976 | 0.976 |
| KernelADASYN | 0.827 | 0.829 | 0.827 | 0.751 | 0.754 | 0.755 | 0.911 | 0.914 | 0.913 | 0.978 | 0.979 | 0.979 | 0.981 | 0.98 | 0.981 |
| kmeans-SMOTE | 0.842 | 0.842 | 0.842 | 0.827 | 0.827 | 0.829 | 0.966 | 0.966 | 0.966 | 0.377 | 0.959 | 0.568 | 0.796 | 0.976 | 0.814 |
| Random-SMOTE | 0.829 | 0.829 | 0.829 | 0.854 | 0.853 | 0.854 | 0.975 | 0.975 | 0.975 | 0.971 | 0.971 | 0.971 | 0.986 | 0.986 | 0.986 |
| Safe-Level-SMOTE | 0.808 | 0.808 | 0.808 | 0.802 | 0.802 | 0.802 | 0.956 | 0.956 | 0.956 | 0.972 | 0.972 | 0.972 | 0.984 | 0.984 | 0.984 |
| SDSMOTE | 0.847 | 0.848 | 0.848 | 0.823 | 0.823 | 0.823 | 0.981 | **0.981** | 0.981 | 0.979 | 0.979 | 0.979 | 0.986 | 0.986 | 0.986 |
| SMOTE | 0.865 | 0.866 | 0.865 | 0.796 | 0.796 | 0.796 | 0.971 | 0.971 | 0.971 | 0.979 | 0.979 | 0.979 | 0.994 | 0.994 | 0.994 |
| SOMO | 0.608 | 0.771 | 0.65 | 0.647 | 0.737 | 0.67 | 0.795 | 0.932 | 0.81 | 0.354 | 0.957 | 0.56 | 0.67 | 0.975 | 0.72 |

| | | | 6 | | | | | | | 1 | | | 2 | | | 2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SVM-balance | **0.891** | **0.897** | **0.892** | 0.903 | 0.907 | 0.904 | 0.975 | 0.976 | 0.975 | 0.967 | 0.967 | 0.967 | 0.987 | 0.988 | 0.977 |
| SYMPROD | 0.852 | 0.853 | 0.853 | 0.833 | 0.831 | 0.834 | 0.972 | 0.972 | 0.972 | 0.984 | 0.984 | 0.984 | 0.989 | 0.988 | 0.989 |
| ASN-SMOTE | 0.6692 | 0.50726 | 0.672 | 0.9104 | 0.756 | 0.911 | 0.7818 | 0.29784 | 0.792 | 0.9678 | 0.50278 | 0.968 | 0.8753 | 0.36762 | 0.88 |
| **HHO-SMOTe** | 0.807 | 0.804 | 0.809 | **0.968** | **0.968** | **0.968** | **0.989** | 0.973 | **0.996** | 0.971 | 0.974 | 0.979 | **0.997** | **0.998** | **0.997** |

In Fig. 3, we assessed G-mean values across 12 data sources using seven SMOTE techniques. A higher G-mean indicates a model's proficiency in both positive and negative class identification, a valuable metric for imbalanced classification. ANS-SMOTE and GASMOTE ranked lower, while ADASYN, SMOTE, RANDOM-SMOTE, and Borderline-SMOTE performed similarly. ADASYN had slightly lower G-mean for "cleveland-0." HHO-SMOTe consistently excelled across various datasets, demonstrating its robustness in imbalanced classification tasks.
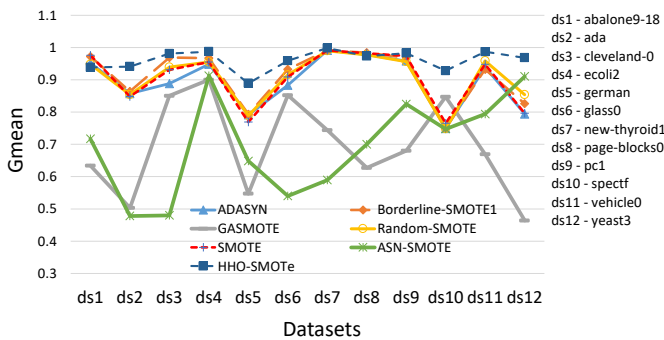


Fig. 3. Comparison of G-mean of seven SMOTE techniques.

In Fig. 4, we compare classification results using F1-score values for various SMOTE algorithms. The F1-score combines precision and recall, indicating a model's ability to balance false positives and false negatives. ANS-SMOTE and GASMOTE performed poorly compared to ADASYN, SMOTE, RANDOM-SMOTE, and Borderline-SMOTE. Conversely, HHO-SMOTe consistently achieved near-perfect F1-Scores (0.9 to 1) across datasets, showing its stability and reliability in diverse classification tasks.
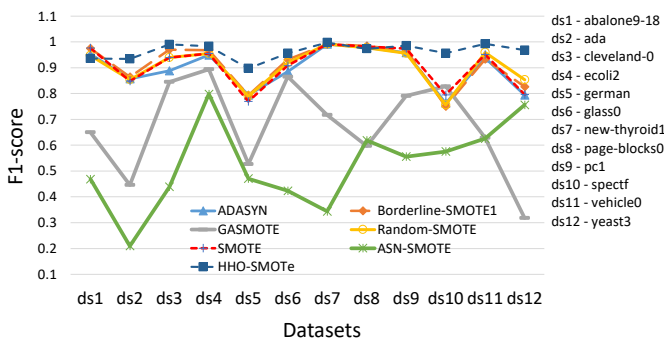


Fig. 4. Comparison of F1-score of seven SMOTE techniques.

In Fig. 5, we conducted a fresh evaluation of our classification studies, focusing on AUC (Area Under the Receiver Operating Characteristic Curve). AUC gauges a binary classification model's overall discrimination ability, considering true positive and false positive rates across different thresholds. The results show ANS-SMOTE and GASMOTE underperformed compared to ADASYN, SMOTE, RANDOM-SMOTe, and Borderline-SMOTE in AUC. In contrast, HHO-SMOTe consistently achieved high AUC values (typically 0.9 to 1), showcasing its adaptability across diverse datasets and confirming its effectiveness in classification tasks, especially when class separation is crucial.
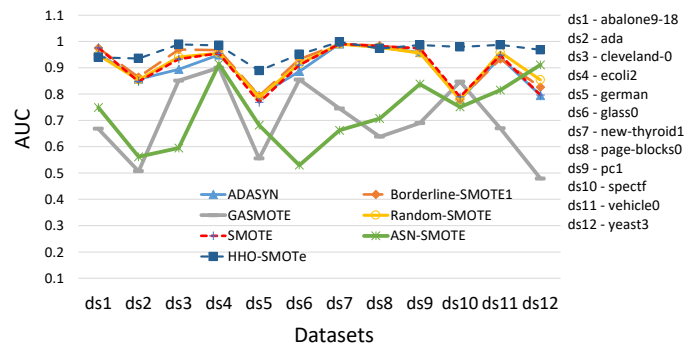


Fig. 5. Comparison of AUC of seven SMOTE techniques.

This research employs the of the well-known credit card fraud detection dataset [46]. The dataset was prepared by the ULB Machine Learning Group, which specializes in big data mining and fraud detection [47]. The dataset covers credit card transactions made by European credit card clients within two days in September 2013. Dataset have 492 fraudulent transactions out of 284807 total. Meanwhile, all attributes except ''Time'' and ''Amount'' are numerical due to transformation carried out on dataset using dimensionality reduction technique called principal component analysis (PCA). ''Amount'' attribute is the cost of the transaction, and ''Time'' attribute is the seconds that elapsed between a transaction and the first transaction in the dataset. ''Class'' is the dependent variable, has a value of 1 for fraudulent and 0 for legitimate.

In Fig. 6, we conducted extensive comparison using credit card fraud dataset known for its vast transaction volume. The goal was to thoroughly evaluate the stability and accuracy of our method within the realm of big data challenges, compared to other techniques. As depicted in the figure, HHO-SMOTe achieved highest AUC score, an impressive 0.96, surpassing other methods with scores below 0.94. These methods ranked in descending order as borderline-2, SMOTE, ADASYN, Borderline1, ASN-SMOTE, GASMOTE, and Random SMOTE. In terms of the F1-Score, all algorithms consistently scored above 0.99, even reaching a perfect score of 1. Regarding the G-mean metric, HHO-SMOTe demonstrated its

superiority with a score exceeding 0.95, while its counterparts fell short with scores below 0.94.
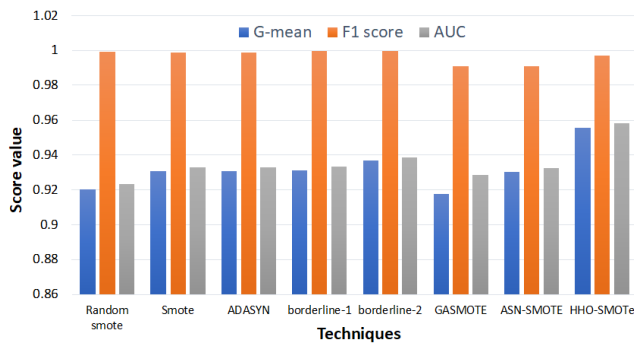


Fig. 6.     Comparison of different SMOTE techniques and HHO-SMOTe using fraud detection dataset.

## VI. CONCLUSION

In summary, the HHO-SMOTe approach represents a significant advancement in effectively addressing complexities of imbalanced datasets in classification tasks. By seamlessly integrating various classifiers with the Harris Hawk search optimization algorithm and SMOTE, we have established a robust framework capable of producing precise and reliable predictions for imbalanced data scenarios. These results hold substantial implications for a wide range of real-world applications where improved classification accuracy and data balance correction play pivotal roles in informed decision-making. Furthermore, our research contributes significantly to the field of imbalanced data handling by shedding light on a potent methodology that enhances the performance of classification models across diverse domains. This amalgamation of state-of-the-art techniques has the potential to mitigate challenges posed by skewed data distributions, ultimately enabling more accurate and trustworthy predictions.

## REFERENCES

[1]    Z Zhang, Chunkai, Ying Zhou, and Yepeng Deng. "VCOS: A novel synergistic oversampling algorithm in binary imbalance classification" IEEE Access  vol7 2019,p145435-145443.

[2]    Fotouhi, Sara, Shahrokh Asadi, and Michael W. Kattan. "A comprehensive data level analysis for cancer diagnosis on imbalanced data" Journal of biomedical informatics vol90, 2019,103089.

[3]    Phua, Clifton, Damminda Alahakoon, and Vincent Lee. "Minority report in fraud detection: classification of skewed data" Acm sigkdd explorations newsletter .vol6,no1, 2004, p50-59.

[4]     Castillo, M. Dolores, and José Ignacio Serrano. "A multistrategy approach for digital text categorization from imbalanced documents" ACM SIGKDD Explorations Newsletter  vol6,no1, 2004.

[5]    Liu, Liang, et al. "Prediction of protein–protein interactions based on PseAA composition and hybrid feature selection" Biochemical and biophysical research communications  vol380,no.2,2009318-322.

[6]    He, Haibo, and Xiaoping Shen. "A Ranked Subspace Learning Method for Gene Expression Data Classification." IC-AI, vol1,2007, 58-364,.

[7]    Soda, Paolo. "A multi-objective optimisation approach for class imbalance learning." Pattern Recognition vol44,no8, ,2011,1801-1810.

[8]    He, Haibo, and Edwardo A. Garcia. "Learning from imbalanced data." IEEE Trans. on knowledge and data engineerin vol21,no.9, 2009,1263-1284.

[9]    Qiong, G. U., et al. "A comparative study of cost-sensitive learning algorithm based on imbalanced data sets.". Microelectron. Comput. vol28,no.8,2009,146–149.

[10]   Chawla, N., et al. "SMOTE: synthetic minority over-sampling technique." Journal of AI research vol16,2002,321-357.

[11]   Heidari, Ali Asghar, et al. "Harris hawks optimization: Algorithm and applications." Future generation computer systems vol97,2019,849-872.

[12]   S. Ebenuwa, M. Sharif, M. Alazab and A. Al-Nemrat, "Variance Ranking Attributes Selection Techniques for Binary Classification Problem in Imbalance Data," in IEEE Access.vol7,2019,24649-24666.

[13]   G. Rekha, A. Tyagi, and R. Krishna, Solving Class Imbalance Problem Using Bagging, Boosting Techniques, with and Without Using Noise Filtering Method. International Journal of Hybrid Intelligent Systems15,no2, 2019, 67–76.

[14]   X. Liu, J. Wu, and Z. Zhou, Exploratory Undersampling for Class-Imbalance Learning. IEEE Transactions on Syst, Man, & Cybernetics, vol. 39, no.2,2009,539-550.

[15]   Jiang, K., Lu, J. & Xia, K. A Novel Algorithm for Imbalance Data Classification Based on Genetic Algorithm Improved SMOTE. Arab J Sci Eng vol41, 2016,3255–3266.

[16]   Nnamoko, Nonso, and Ioannis Korkontzelos. "Efficient treatment of outliers and class imbalance for diabetes prediction." Artificial intelligence in medicine 104 ,2020, 101815.

[17]   Liu, Shigang, et al. "Addressing the class imbalance problem in twitter spam detection using ensemble learning." Computers & Security vol69, 2017, 35-49.

[18]   Ma, J., Afolabi, D.O., Ren, J. et al. "Predicting Seminal Quality via Imbalanced Learning with Evolutionary Safe-Level Synthetic Minority Over-Sampling Technique". Cogn Comput vol.13, 2021, 833–844.

[19]   Susan, S, Kumar, A. "The balancing trick:Optimized sampling of imbalanced datasets A brief survey of the recent State of the Art". Engineering Reports. 2021; 3: e12298.

[20]   Tanapol Kosolwattana, Chenang Liu, Renjie Hu, Shizhong Han, Hua Chen and Ying Lin. "A self-inspected adaptive SMOTE algorithm (SASMOTE) for highly imbalanced data classification in healthcare". BioData Mining16, 15. 2023.

[21]   J. Wang; M. Xu; H. Wang; J. Zhang. "Classification of Imbalanced Data by Using the SMOTE Algorithm and Locally Linear Embedding", 2006 8th international Conference on Signal Processing,2006, 9505808.

[22]   P. Jeatrakul, K.W. Wong and C.C. Fung ,"Classification of Imbalanced Data by Combining the Complementary Neural Network and SMOTE Algorithm", Neural Information Processing Models &App, Vol6444,no.2,2010,152-159.

[23]   Aimin Zhang, Hualong Yu, Zhangjun Huan, Xibei Yang,."SMOTE-RkNN:A hybrid re-sampling method based on SMOTE and reverse k-nearest neighbors";Info. Sci.Vol.595,2022,p 70-88.

[24]   M. Shehab, I. Mashal, Z. Momani, M. Shambour, A. AL-Badareen, S. Al-Dabet, N. Bataina, A. Ratib Alsoud,"Harris Hawks Optimization Algorithm: Variants and Applications",Archives of Computational Methods in Engineering vol. 29, 2022, p5579–5603.

[25]   B. Tripathy, P. Maddikunta, Q. Pham,T. Kapal Dev, S. Pandya, and B. ElHalawany."Harris Hawk Optimization:A Survey on Variants and Applications" , Vol 2022 | Article ID 2218594 |.

[26]    J.C. Bednarz, "Cooperative hunting in harris' hawks (parabuteo unicinctus", Science vol239 ,1988, 1525.

[27]   Fathimathul Rajeena,Walaa N. Ismail, Mona A.S. A Metaheuristic Harris Hawks Optimization Algorithm for Weed Detection Using Drone Images, (ISSN 2076-3417).  2023 , 13(12), 7083.

[28]   Su. Muruganandam, Vij. Natarajan, Raja Soos., Raj. Murugesan HHO-ACO hybridized load balancing technique in cloud computing, Feb 2023 Inter. Jour. of Info. Tech. Vol 15, P 1357–1365.

[29]   Bisong, E.: Google Colaboratory, pp. 5964. Apress, Berkeley, CA 2019.

[30]   He, H. and Bai, Y. and Garcia, E. A. and Li, S., "ADASYN: adaptive synthetic sampling approach for imbalanced learning", Proceedings of IJCNN, 2008, p. 1322—1328.

[31] J. Yun, J. Ha, and J. Lee, "Automatic Determination of Neighborhood Size in SMOTE", Proceedings of 10th International Conf. on Ubiquitous Info. Management and Comm.,2016, p. 100z1—100:8

[32] W Siriseriwan, and K. Sinapiromsaran, "Adaptive neighbor synthetic minority oversampling technique under 1NN outcast handling",Songklanakarin Jour of Science and Tech. vol39,no5,2017, p. 565-576

[33] Hui Han, Wen-Yuan Wang & Bing-Huan Mao, "Borderline-SMOTE: A New Over-Sampling Method in Imbalanced Data Sets Learning", Advances in Intelligent Computing, vol6,2005, p. 878-887.

[34] De La Calleja, J. and Fuentes, O., "A distance-based over-sampling method for learning from imbalanced datasets", Proceedings of the 20th International Florida Artificial Intelligence, 2007, p. 634-635

[35] Sandhan, T. and Choi, J. Y., "Handling Imbalanced Datasets by Partially Guided Hybrid Sampling for Pattern Recognition", 2014 22nd International Conference on Pattern Recognition, 2014, p. 1449-1453

[36] Hansoo Lee and Jonggeun Kim and Sungshin Kim, "Gaussian-Based SMOTE Algorithm for Solving Skewed Class Distributions", Int. J. Fuzzy Logic and Intelligent Systems,Vol 17,no4, 2017, p. 229-234

[37] Tang, B. and He, H., "KernelADASYN: Kernel based adaptive synthetic data generation for imbalanced learning", 2015 IEEE Congress on Evolutionary Computation (CEC), 2015, p. 664-671

[38] G. Douzas and F. Bacao and F. Last, "Improving imbalanced learning through a heuristic oversampling method based on k-means and SMOTE", Information Sciences,Vol 465, 2018, p. 1-20.

[39] Don, "A New Over-Sampling Approach: Random-SMOTE for Learning from Imbalanced Data Sets", Knowledge Scienc,Vol 7091, 2011 p. 43-352.

[40] Bunkhumpornpat, C. and Sinapiromsaran, K. and Lursinsap, C., "Safe-Level-SMOTE: Safe-Level-Synthetic Minority Over-Sampling TEchnique for Handling the Class Imbalanced Problem", Proceedings 13th Pacific-Asia Conf. on Advances in Knowledge Discovery and Data Mining, vol volume 5476, 2009, p. 475-482.

[41] Li, K. and Zhang, W. and Lu, Q. and Fang, X., "An Improved SMOTE Imbalanced Data Classification Method Based on Support Degree", Inter. Conf .on Identification, Info. and Knowl. in ITO, 2014, p. 34-38

[42] G. Douzas and F. Bacao, "Self-Organizing Map Oversampling (SOMO) for imbalanced data set learning", Expert Systems with Applications, Vol.42,2017, p. 40-52

[43] Farquad, M., Bose, I., "Preprocessing Unbalanced Data Using Support Vector Machine", Decis Support Syst.,Vol53,no1,2012,p. 226-233.

[44] Kunakorntum, I. and Hinthong, W. and Phunchongharn, P.,"A Synthetic Minority Based on Probabilistic Distribution (SyMProD) Oversampling for Imbalanced Datasets", IEEE Access, 2020, p. 114692-114704.

[45] X. Yi, Y. Xu, Q. Hu, S. Krishnamoorthy, W. Li, Z. Tang. "ASN-SMOTE: a synthetic minority oversampling method with adaptive qualified synthesizer selection". Complex & Intel. Systems, Vol.8, 2022, p.2247–2272.

[46] Credit Card Fraud Detection. Accessed: Oct. 2021, 26. [Online]. Available: https://kaggle.com/mlg-ulb/creditcardfraud.

[47] H. Patel, D. S. Rajput, G. T. Reddy, C. Iwendi, A. K. Bashir, and O. Jo, ''A review on classification of imbalanced data for wireless sensor networks,'' Int. J. Distrib. Sensor Netw., vol. 16, no. 4, 2022.

# A Multitask Learning System for Trait-based Automated Short Answer Scoring

Dadi Ramesh[1*], Suresh Kumar Sanampudi[2]

School of Computer Science and Artificial Intelligence, SR University, Warangal, India[1]
Research Scholar in JNTU, Hyderabad, India[1]
Department of Information Technology-JNTUH College of Engineering Jagitial,
Nachupally, (Kondagattu), Jagtial dist Telangana, India[2]

*Abstract*—**Evaluating students' responses and providing feedback in the education system is widely acknowledged. However, while most research on Automated Essay Scoring (AES) has focused on generating a final score for given responses, only a few studies have attempted to generate feedback. These studies often rely on statistical features and fail to capture coherence and content-based features. To address this gap, we proposed a multitask learning system that can capture linguistic, coherence, and content-based features with Bidirectional Encoder Representations from Transformers (BERT) sentence by sentence and generate overall essay and trait scores. Our proposed system outperformed other existing models, achieving Quadratic Weighted Kappa (QWK) scores of 0.766, 0.69, and 0.701 compared to human rater scores. We evaluated our model on the Automated Student Assessment Prize (ASAP) Kaggle and operating system (OS) data set. When compared with other prescribed models proposed to multitask learning system is a promising step towards more effective and comprehensive writing assessment and feedback.**

*Keywords—Sentence embedding; coherence; LSTM; short answer scoring; trait score*

## I. INTRODUCTION

Evaluating student responses and providing feedback can improve the student's learning abilities in the education system. However, while AES has been a research focus in recent years, most studies have concentrated on generating a final score for student responses rather than providing feedback. In a few studies like [6, 13, 14, 15 and 16] systems, they did not attempt to generate feedback. However, these approaches extract statistical features for the final score and trait score generation, which did not fully capture students' responses' coherence and content-based features.

There are two main ways to provide feedback to students on their writing: gaze behavior by Mathias and Bhattacharyya [13, 14] and providing trait scores [6, 17, 14, 16, 25 and 26]. Gaze behavior refers to analyzing the visual behaviors of readers as they read a text, such as eye movement patterns. This methodology offers insights into readability, syntax, and fluency within the writing. However, trait scores evaluate specific writing attributes like organization, word choice, and coherence. These traits furnish more intricate insights into a student's writing than a simple overarching score.

Despite the strides made in deep learning and natural language processing, furnishing feedback on aspects such as organization, word choice, and syntax can benefit student learning more than just presenting a general score. As Woods [23] exemplified, this form of feedback equips students with a deeper comprehension of how to enhance their writing competencies holistically. For instance, feedback on organization assists students in grasping effective structuring techniques for their compositions. In contrast, feedback on word choice can help students select appropriate words to convey their ideas more clearly.

To accurately assess the student's response and provide comprehensive scoring and feedback, extracting both semantic and linguistic features from the text is essential. Relying solely on statistical features like Term Frequency and Inverse Document Frequency (TF-IDF), a bag of words, and N-gram models may not sufficiently capture the content and coherence of the student's answer. These traditional methods mainly focus on the frequency and distribution of individual words or phrases. In contrast, modern natural language processing (NLP) models such as word2vec [12] and Global vectors for word representation [7] can effectively capture semantic features by representing words in a continuous vector space. However, it is worth noting that these models like [1, 3, 4, and 13] primarily operate at the word level and may encounter difficulties when handling complex or polysynthetic words.

Deep learning models can be employed to address the need for capturing content, coherence, and maintaining the sequence of words. Recurrent Neural Networks (RNNs), particularly models like Long Short-Term Memory (LSTM) or Gated Recurrent Units (GRUs), are commonly used for sequential data processing in NLP. These models like [13, 20, 21, 22 and 24], can analyze text at the sentence or paragraph level, considering the contextual information preceding words provide. Ridley et al. in [18] implemented a system for cross prompt essay scoring with semi supervised learning; furthermore, maintaining an internal state can capture dependencies and semantic relationships between words.

A deep learning model trained on a suitable dataset can be developed in the context of grading and providing feedback on student responses. This model would take the student response as input, process it using an RNN or similar architecture, and generate a final score and trait score. The training data for such a model ideally includes labeled examples of student responses paired with their corresponding scores and traits. This way, the model can learn to recognize patterns and

---

*Corresponding Author

associations between the input text and the desired output scores.

Overall, combining advanced NLP techniques, deep learning models, and appropriate training data can help extract content and coherence features while maintaining the sequence of words, thereby enabling the generation of accurate scores and feedback on student responses.

*A. Contribution*

- Our AES system captures sentence-level features from responses, enhancing essay analysis by highlighting key traits and patterns at this granular level. These features provide valuable insights into essay quality and structure.

- Employing LSTM, a type of recurrent neural network, we assign scores to essays. LSTM's strength in capturing context and relationships among sentences makes it ideal for modeling and analyzing essays.

- Our AES system produces three scores - overall, organization, and word choice. This trio offers a multi-faceted evaluation of essays, assessing different writing aspects like coherence, logical flow, and vocabulary sophistication. Additionally, we compare our model against established approaches to demonstrate its superiority.

- We test it on two datasets, a public dataset and a domain-specific dataset. Testing on different datasets helps evaluate the generalizability of our model across different domains or essay topics. It demonstrates the versatility and adaptability of our AES system.

Organization: The remainder of the paper is organized as follows: Section II illustrates related works on various evaluation systems and challenges. Section III discusses the proposed model and the data set used for our models. Section IV discusses the results and analysis of our model on various factors and test cases. Finally, Section V discusses the conclusion and future work.

## II. RELATED WORK

Automated Essay Scoring (AES) has primarily focused on generating a final score for student responses rather than providing detailed feedback. This emphasis on scoring is often driven by the need for standardized assessment, where the primary goal is to assign a numerical score that reflects the quality of the essay. So many researchers worked on the final score generation for the given response. Various systems, such as those developed by [4, 5, 9, and 10] as well as [11] have adopted distinct approaches. These approaches involve combining different elements, such as statistical features and word-level attributes, and training machine learning or neural network models. However, a noteworthy aspect is that these methodologies need to effectively encapsulate the entirety of the content within the essays into their respective vectors.

Generating feedback is more challenging because it requires understanding the student's response's content, structure, and coherence. While some AES systems [2, 8, 16 and 23] provide generic feedback based on predefined patterns

or rules, the quality and specificity of this feedback may be limited.

However, there has been increasing interest in developing AES systems that go beyond scoring and provide more meaningful feedback to students. With advancements in natural language processing and deep learning, researchers are exploring approaches to extract fine-grained linguistic and semantic features from essays, which can be used to provide personalized feedback.

Ridley et al. in [17, 18] introduced a method that utilizes a trait-attention mechanism and a multi-task architecture to predict student essays' overall and individual trait scores. They conducted extensive experiments on the ASAP dataset, specifically prompt-2, to demonstrate the effectiveness of their approach for prompt-specific trait scoring and cross-prompt AES methods. To optimize model performance, researchers integrated syntactical elements by applying POS embedding. They employed LSTM models for generating comprehensive scores encompassing overall performance and specific traits. Additionally, Mathias and Bhattacharyya in [15] proposed a neural network model targeting word-level semantic features, enhancing the granularity of assessment. The common thread in these approaches is using Long Short-Term Memory (LSTM) models to predict multiple trait scores, enabling intricate essay evaluation. This technique captures nuanced semantic information at the word level, shedding light on the multifaceted traits manifested within the essays.

Hussein et al. in [6] focused on the ASAP dataset, employing LSTM to generate trait scores. Their model was tailored explicitly, capturing relevant patterns and features for accurate score prediction.

Woods et al. in [23] employed standard logistic regression to derive trait scores, providing a comprehensive assessment avenue. Although simpler than LSTM, logistic regression still yields valuable predictions and insights into trait scores.

Ohta et al. in [16] introduced a versatile model generating various scores, spanning overall evaluation, organizational development, and language proficiency. Their approach likely amalgamates techniques, potentially encompassing deep learning models such as LSTM, to predict and appraise different essay facets holistically.

These studies underscore diverse techniques and methodologies for forecasting trait scores in student essays. Each approach contributes unique insights, leveraging attention mechanisms, multi-task architectures, syntactical and statistical attributes, and the power of LSTM and logistic regression models for robust evaluation. In addition, these diverse methods contribute to the field by providing various options for assessing and providing feedback on different aspects of essay writing.

## III. METHODOLOGY

We proposed that the AES system incorporates sentence-based text embeddings and LSTM to capture essay coherence and content. This model is implemented on top of [19] it generates multiple scores, including overall, organization, and word choice scores, providing a comprehensive evaluation.

Using both standard and domain-specific datasets strengthens the credibility and generalizability of our system. In addition, robustness testing ensures its resilience in handling adversarial responses. The architecture diagram Fig. 1 visually represents the system's components and integration, facilitating replication and implementation.
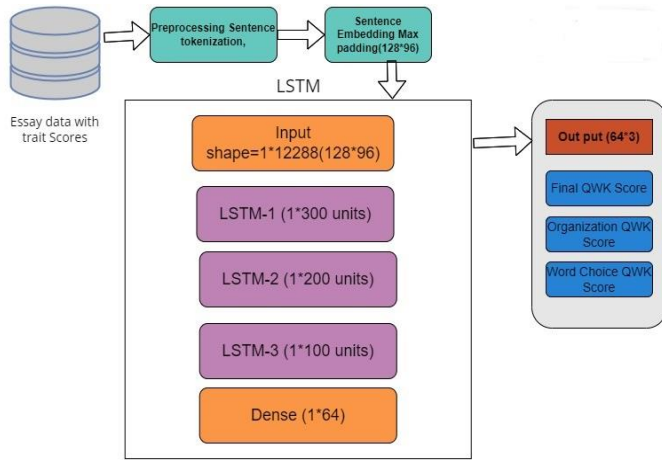


Fig. 1. Architecture of content based essay scoring system with LSTM.

### A. Data Set

In the context of our AES systems, we used the ASAP Kaggle dataset. This dataset comprises 12,978 essays written by students in grades 8 to 10. The essays were generated in response to eight different prompts provided to the students. Every prompt comprises a collection of 1500 or more essays, all of which have been evaluated by two individual raters. Prompts 3, 4, 5, and 6 pertain to essays that rely on specific sources for their content, whereas the remaining prompts fall under the "others" category.

For our trait-based essay scoring approach, we specifically focused on Prompt 2 during our study. This allowed us to analyze and evaluate the essays based on specific traits and criteria relevant to that prompt. Table I and Table II exemplifies a detailed description of the essay dataset, including the number of essays, prompts, and raters involved.

TABLE I. AUTOMATED STUDENT ASSESSMENT PRIZE (ASAP) DATA SET FOR ESSAY SCORING

| Prompt _id | Prompt wise total number of essays | Average Number of words in an essay | Score range (min-max) |
|---|---|---|---|
| 1 | 1783 | 350 | 2-12 |
| 2 | 1800 | 350 | 1-6 |
| 3 | 1726 | 150 | 0-3 |
| 4 | 1772 | 150 | 0-3 |
| 5 | 1805 | 150 | 0-4 |
| 6 | 1800 | 150 | 0-4 |
| 7 | 1569 | 250 | 0-30 |
| 8 | 723 | 650 | 0-60 |

TABLE II. OPERATING SYSTEM DATA SET
(HTTPS://GITHUB.COM/RAMESHDADI/OS-DATA_1-SET-FOR-AES)

| Prompt-id | Prompt | Prompt wise number of essays | Prompt wise maximum number of sentences | Rating range (min to max) |
|---|---|---|---|---|
| 1 | Explain about operating system? | 516 | 23 | |
| 2 | Explain the advantages of a multiprocessor system? | 596 | 21 | |
| 3 | Explain how operating system handles multiple tasks at a time? | 312 | 19 | 0-5 |
| 4 | Difference between single processor and multiprocessor operating systems? | 513 | 19 | |
| 5 | Explain different scheduling algorithm? | 453 | 15 | |

In order to evaluate the performance of AES systems on domain-specific essays in the field of operating systems (OS), we created a custom dataset in addition to the ASAP dataset. This dataset was purposely crafted to address the field of operating systems. We formulated five fundamental inquiries concerning operating systems and then distributed these inquiries as assignments to students across various engineering colleges.

Upon gathering the responses, we meticulously eliminated duplicated or repeated submissions, culminating in a dataset comprising 2390 unique responses from 626 students. To ensure the dataset's dependability and excellence, we engaged in the expertise of two subject matter specialists. These professionals evaluated each essay, assigning scores for overall impression, organization, and word choice. This approach provided thorough and detailed evaluations of the students' written reactions.

By incorporating this tailor-made dataset, we intend to streamline the assessment of AES systems in their proficiency and accuracy when evaluating essays that specifically revolve around the operating systems realm. Furthermore, this dataset is a valuable asset for honing and optimizing AES systems within this domain.

The agreement between the two human raters was assessed using the QWK score. The computed QWK scores for the overall impression, organization, and word choice were 0.842, 0.879, and 0.912, respectively. These scores indicate a substantial agreement between the raters.

Table II illustrates a detailed description of the OS dataset, presenting information about the number of responses, students, and expert evaluators involved. Fig. 2 illustrates the agreement between the two raters, further illustrating the consistency in their evaluations.
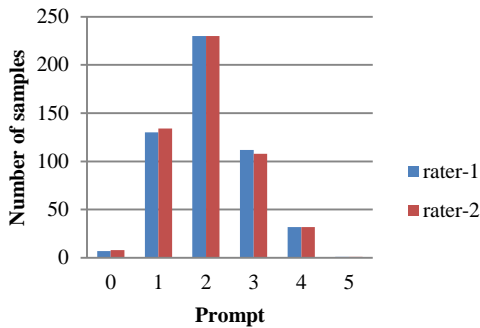
Fig. 2. Agreement between rater-1 and rater -2 (organization score for OS dataset).

### B. Sentence Embedding

Converting text into vectors that effectively capture context and semantics is a complex task in natural language processing (NLP). Conventional embedding methods such as word2vec and GloVe primarily concentrate on converting text into word vectors. However, these methods come with certain constraints. They must thoroughly account for the words around a particular word and how their meanings change in different contexts. Furthermore, these techniques encounter difficulties when dealing with words with multiple meanings (polysemous words), which can result in a lack of accuracy in capturing the intended sense of the word.

Furthermore, approaches such as averaging word vectors to derive sentence vectors cannot capture the nuanced information in the original sentence. This oversimplification needs to be revised to include the intricate relationships and interactions between words, leading to a loss of important contextual details.

To address these challenges, more advanced techniques in NLP are being developed. These techniques aim to overcome the limitations of traditional methods by capturing a richer representation of text that incorporates both context and semantics more comprehensively. Our model utilizes Sentence BERT, a sentence embedding technique, to address these limitations. Sentence BERT introduces a dynamic approach to converting essays into vectors, considering the contextual and semantic aspects of individual sentences. Unlike traditional embedding techniques, Sentence BERT's vector representation captures a more comprehensive understanding of the original text.

The process begins by removing special symbols like "@" and "#" from the essays and tokenizing them into sentences. The ASAP and OS datasets have specific limitations on the maximum number of sentences per essay. The maximum number of sentences per essay for the ASAP dataset is 96, while for the OS dataset, it is 23.

To obtain sentence embeddings using a pre-trained transformer model, such as Sentence BERT, each sentence is transformed into a 128-dimensional vector representation. As a result, for an essay from the ASAP dataset, there will be 96 * 128-dimensional vectors, considering the maximum number

of sentences. Similarly, for an essay from the OS dataset, there will be 23 * 128-dimensional vectors based on the respective maximum number of sentences.

Finally, to ensure consistent dimensions, all essays are padded to have 96 * 128-dimensional vectors for the ASAP dataset and 23 * 128-dimensional vectors for the OS dataset. The maximum number of sentences in each dataset determines the padding size.

### C. Model

To capture the coherence, cohesion, and linguistic features of the essay, we embedded all the sentences of the essays without removing stop words. So it allows the model to consider the entire text and capture the overall coherence of the essay.

In order to handle the sequence of sentence embeddings, we utilized LSTM (Long Short-Term Memory), a type of recurrent neural network (RNN). LSTM is designed to effectively process sequential information while retaining the memory of previous inputs.

The LSTM architecture incorporates various gates, as depicted in Fig. 3. These gates, including the input gate equation [2], forget gate [1], output gate [3], and context gate [4], collaborate to facilitate the processing and storage of long-term dependencies necessary for feature extraction.

The input gate controls the flow of information into the memory cell, while the forget gate determines which information to discard from the previous cell state. The output gate regulates the output information from the memory cell, and the context gate manages the update of the memory cell content.

$$f_t = \sigma g(w_f x_t + u_f h_{t-1} + b_f) \qquad (1)$$

$$i_t = \sigma g(w_i x_t + u_i h_{t-1} + b_i) \qquad (2)$$

$$o_t = \sigma g(w_o x_t + u_o h_{t-1} + b_o) \qquad (3)$$

$$C_t = tanh(w_c x_t + u_c h_t + b_c) \qquad (4)$$
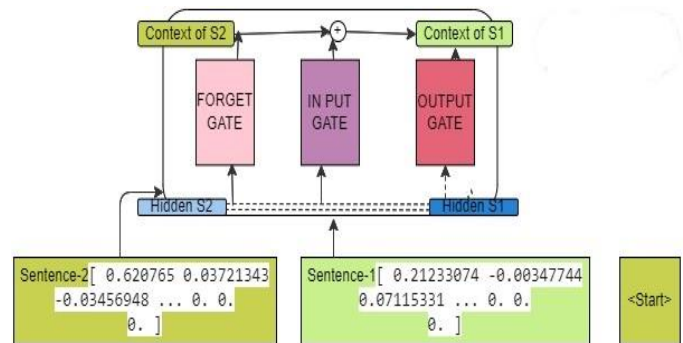


Fig. 3. Contexts generation from sentences in LSTM.

### D. Implementation and Training LSTM

In our methodology, we started by turning essays into organized sets of numbers using a technique called Sentence BERT. These sets were then made consistent by adding extra information and aligning them with the largest essay size of 96 by 128. After this, we transformed these sets of numbers into

another type of organized sets with three dimensions, getting them ready for neural network training.

To construct our LSTM model, we devised a configuration comprising five tiers of LSTM units intricately assembled. Each tier encompassed components that facilitated the absorption of information, dissemination of information, and context management. This structural design proved pivotal in monitoring the interconnections spanning distinct sections of the essays.

To enhance the efficacy of our model, we adopted the RMSprop optimization technique, concentrating on minimizing the mean discrepancy between our forecasts and the actual results. To counteract the risk of our model fixating excessively on idiosyncrasies within the training data, we integrated a mechanism that intermittently deactivated specific model segments during the training phase. Furthermore, we established a predetermined pace for how our model assimilates knowledge from the data. Our model's response to data inputs was governed by a selected mathematical function termed ReLU. Throughout the model training process, we implemented a strategy known as 5-fold cross-validation. This divided our sets of essay information into separate groups for training, testing, and validating, with a specific ratio assigned to each for both the ASAP and OS datasets.

We trained our model for different amount of time (10, 15, 20, and 35 times), trying to find the best settings, and then we checked how well it performed. We used a QWK measure to see how close the model's ratings were to human ratings, an essential standard for automated essay scoring.

For each round of cross-validation, we calculated the QWK score. Finally, we chose the model that worked the best on the training data to make predictions on the test data. A graph (see Fig. 5) showed how the model learned and did on new data where batch size 24, demonstrating that it learned well without getting too stuck on the training details.

We are applied the same hyperparameters and cross-validation technique to ensure consistency in our experimentation and evaluation process between the ASAP and OS datasets. This allows for a fair comparison and assessment of our model's performance on different essay datasets.

## IV. RESULT AND DISCUSSIONS

We conducted experiments using the ASAP and OS datasets to develop trait-based AES (Automated Essay Scoring) systems. Our proposed model exhibited the best results on both datasets. Furthermore, we approached the training of our model on a prompt-by-prompt basis and subsequently computed the corresponding training and validation losses. This process is visualized in Fig. 4 and Fig. 5. The figure illustrates the learning process for batch size 32, which is getting overfitted after some iteration. But from Fig. 5, when we used a batch size of 16, the training and validation losses consistently decreased and overlapped each other.

We achieved superior results when comparing our proposed models to other baseline models, specifically on prompt-2 of the ASAP dataset. We used the average QWK

(Quadratic Weighted Kappa) score for each trait. As shown in Table III, our sentence embedding-LSTM model outperformed other models and demonstrated consistency with human rater scores. However, the integrated and word embedding models could have effectively captured sentence coherence. It is worth noting that while neural networks tend to achieve high QWK scores, they may not fully capture the text's coherence. The models implemented with word embeddings required maintaining word order, which could impact coherence. Additionally, word embedding models may struggle with polysemous words, potentially leading to a lack of coherence in the text.

Our proposed model performed well on the Domain-specific data set, specifically regarding the final, organization, and word choice scores. This indicates that our model is robust and consistently delivers good results.

Table IV compares our proposed model and other approaches on the Domain-specific data set, demonstrating the superiority of our model across multiple scoring criteria. In addition, the consistent performance of our model suggests its reliability and effectiveness in evaluating essays within the specific domain. Fig. 6 illustrates the comparison of the actual score and predicted scores of our models. From this, we can observe that both colors are overlapped maximum, which indicates that our model predicted the correct scores for test data.
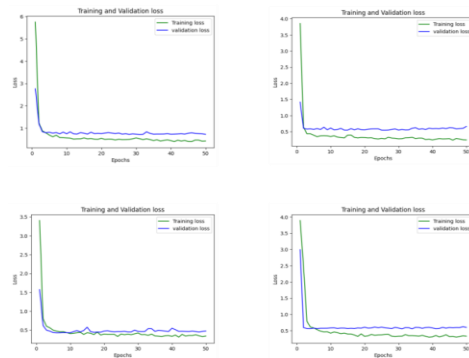


Fig. 4. Prompt wise training and validation loss of sent-LSTM model (batch size=32).
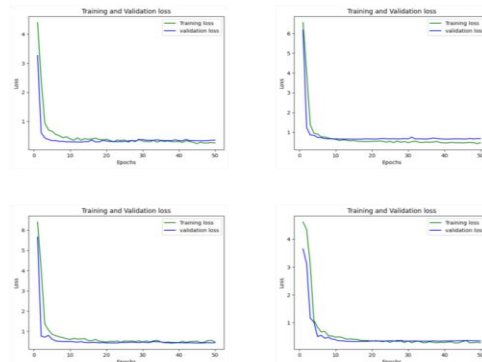


Fig. 5. Prompt wise training and validation loss of sent-LSTM model (batch size=16).

TABLE III.    NEURAL NETWORK MODEL HYPER PARAMETERS AND TRAINED VALUES

| Layer | parameter | Value |
|-------|-----------|-------|
| *Embedding* | Sentence Embedding (BERT) | 128 size vectors for each sentence |
| *Input and output* | Input size output | (1,96,128), (1, 23,128) 1*3 |
| *LSTM layers* | No of layers | 5 |
| *LSTM Units* | LSTM Units | 300 |
| *Hidden* | Hidden units | 200,100 |
| *Drop out* | Dropout rate Recurrent Drop out | 0.4 0.5 |
| *Others* | Epochs Batch size Learning Rate Optimizer | 35 32 0.001 Adam |

TABLE IV.    COMPARISONS OF RESULTS ON ASAP DATA SET PROMPT-2(QWK SCORE) WITH PRESCRIBED MODELS

| System | Overall score | Organization | Word choice | ASAP dataset | Remarks |
|--------|---------------|--------------|-------------|--------------|---------|
| [17] | 0.453 | 0.243 | 0.416 | All prompts | Word embedding model |
| [14] | 0.563 | 0.551 | 0.531 | Prompt-2 | |
| [6] | 0.402 | 0.256 | 0.402 | All prompts | |
| [1] | 0.600 | 0.570 | 0.583 | Prompt-2 | |
| [4] | 0.617 | 0.623 | 0.630 | Prompt-2 | |
| Sent-LSTM model | 0.691 | 0.677 | 0.679 | Prompt-2 | Sentence embedding model |
| Sent-LSTM model | 0.672 | 0.66 | 0.673 | OS-data set | Sentence embedding model |



Fig. 6.    Comparisons of actual and predicted score of sent-LSTM, top row batch size are 16, and bottom row batch size is 32.

## V. CONCLUSION

We introduced a novel approach for an AES system focusing on trait-based assessment. To capture the coherence patterns between sentences in an essay, the model employed a preprocessing step where each sentence was embedded individually. This sequence-to-sequence approach allows the model to capture the overall coherence and flow of ideas within the essay. The embedded sentences were then fed into a recurrent neural network, specifically an LSTM, for training.

In our study, we compared our Sentence Embedding-LSTM model with baseline models commonly used in AES. The results showed that our proposed model performed well and outperformed the other baseline models in terms of its ability to capture coherence. So, our approach successfully addressed the challenge of maintaining coherence in the generated essays.

Leveraging sentence embedding and training on recurrent neural networks model demonstrated its effectiveness in capturing the overall organization and coherence of the essays. However, our approach has the potential to provide more reliable and accurate automated scoring while preserving the coherence of the generated texts.

In the future, we will implement a system to provide all traits like grammar and sentence organization and provide the students Qualitative feedback in text format. And we also improve model performance.

## REFERENCES

[1] Cozma, M., Butnaru, A. M., & Ionescu, R. T. (2018). Automated essay scoring with string kernels and word embeddings. arXiv preprint arXiv:1804.07954. https://doi.org/10.48550/arXiv.1804.07954

[2] Carlile, W., Gurrapadi, N., Ke, Z., & Ng, V. (2018, July). Give me more feedback: Annotating argument persuasiveness and related attributes in student essays. In Proceedings of the 56th Annual Meeting of the Association for Computational Linguistics (Volume 1: Long Papers) (pp. 621-631). DOI:10.18653/v1/P18-1058

[3] Dasgupta, T., Naskar, A., Dey, L., &Saha, R. (2018, July). Augmenting textual qualitative features in deep convolution recurrent neural network for automatic essay scoring. In Proceedings of the 5th Workshop on Natural Language Processing Techniques for Educational Applications (pp. 93-102). DOI:10.18653/v1/W18-3713

[4] Dong F, Zhang Y, &Yang J (2017) Attention-based recurrent convolutional neural network for automatic essay scoring. In: Proceedings of the 21st Conference on Computational Natural Language Learning (CoNLL 2017) p 153–162. DOI: 10.18653/v1/K17-1017

[5] Fernandez, N., Ghosh, A., Liu, N., Wang, Z., Choffin, B., Baraniuk, R., & Lan, A. (2022). Automated Scoring for Reading Comprehension via In-context BERT Tuning. arXiv preprint arXiv:2205.09864. https://doi.org/10.48550/arXiv.2205.09864

[6] Hussein, M. A., Hassan, H. A., & Nassef, M. (2020). A trait-based deep learning automated essay scoring system with adaptive feedback. International Journal of Advanced Computer Science and Applications, 11(5). DOI : 10.14569/IJACSA.2020.0110538

[7] Pennington, J., Socher, R., & Manning, C.D. (2014). GloVe: Global Vectors for Word Representation. *Conference on Empirical Methods in Natural Language Processing*. pages 1532–1543, Doha, Qatar. Association for Computational Linguistics.DOI:10.3115/v1/D14-1162

[8] Ke, Z., Carlile, W., Gurrapadi, N., & Ng, V. (2018, July). Learning to Give Feedback: Modeling Attributes Affecting Argument Persuasiveness in Student Essays. In IJCAI (pp. 4130-4136). https://doi.org/10.24963/ijcai.2018/574

[9] Kumar, Y., Aggarwal, S., Mahata, D., Shah, R. R., Kumaraguru, P., & Zimmermann, R. (2019, July). Get it scored using autosas—an automated system for scoring short answers. In Proceedings of the AAAI Conference on Artificial Intelligence (Vol. 33, No. 01, pp. 9662-9669). DOI: https://doi.org/10.1609/aaai.v33i01.33019662

[10] Kabra, A., Bhatia, M., Kumar, Y., Li, J. J., Jin, D., & Shah, R. R. (2020). Calling Out Bluff: Evaluation Toolkit for Robustness Testing Of Automatic Essay Scoring Systems. *arXiv preprint arXiv:2007.06796*.

[11] Lun, J., Zhu, J., Tang, Y., & Yang, M. (2020). Multiple Data Augmentation Strategies for Improving Performance on Automatic Short Answer Scoring. *Proceedings of the AAAI Conference on Artificial Intelligence*, *34*(09), 13389-13396. https://doi.org/10.1609/aaai.v34i09.7062

[12] Mikolov, T., Chen, K., Corrado, G., & Dean, J. (2013). Efficient estimation of word representations in vector space. arXiv preprint arXiv:1301.3781. https://doi.org/10.48550/arXiv.1301.3781

[13] Mathias S, Bhattacharyya P (2018) ASAP++: Enriching the ASAP automated essay grading dataset with essay attribute scores. In: Proceedings of the Eleventh International Conference on Language Resources and Evaluation (LREC 2018)

[14] Mathias, S., & Bhattacharyya, P. (2020, July). Can neural networks automatically score essay traits?. In Proceedings of the Fifteenth Workshop on Innovative Use of NLP for Building Educational Applications (pp. 85-91). DOI:10.18653/v1/2020.bea-1.8

[15] Mathias, S., Murthy, R., Kanojia, D., Mishra, A., & Bhattacharyya, P. (2020). Happy are those who grade without seeing: A multi-task learning approach to grade essays using gaze behaviour. arXiv preprint arXiv:2005.12078.

[16] Ohta, R., Plakans, L. M., & Gebril, A. (2018). Integrated writing scores based on holistic and multi-trait scales: A generalizability analysis. Assessing Writing, 38, 21-36. doi.org/10.1016/j.asw.2018.08.001.

[17] Ridley, R., He, L., Dai, X., Huang, S., & Chen, J. (2020). Prompt Agnostic Essay Scorer: A Domain Generalization Approach to Cross-prompt Automated Essay Scoring. arXiv preprint arXiv:2008.01441. https://doi.org/10.48550/arXiv.2008.01441

[18] Ridley, R., He, L., Dai, X. Y., Huang, S., & Chen, J. (2021, May). Automated cross-prompt scoring of essay traits. In Proceedings of the AAAI conference on artificial intelligence (Vol. 35, No. 15, pp. 13745-13753). https://doi.org/10.1609/aaai.v35i15.17620

[19] Ramesh, D., & Sanampudi, S. K. (2022, November). Coherence Based Automatic Essay Scoring Using Sentence Embedding and Recurrent Neural Networks. In Speech and Computer: 24th International Conference, SPECOM 2022, Gurugram, India, November 14–16, 2022, Proceedings (pp. 139-154). Cham: Springer International publishing. https://doi.org/10.1007/978-3-031-20980-2_13

[20] Singh, S., Pupneja, A., Mital, S., Shah, C., Bawkar, M., Gupta, L. P., ... & Shah, R. R. (2023). H-AES: Towards Automated Essay Scoring for Hindi. arXiv preprint arXiv:2302.14635.

[21] Taghipour, K., & Ng, H. T. (2016, November). A neural approach to automated essay scoring. In Proceedings of the 2016 conference on empirical methods in natural language processing (pp. 1882-1891). DOI:10.18653/v1/D16-1193.

[22] Uto, M., & Okano, M. (2021). Learning automated essay scoring models using item-response-theory-based scores to decrease effects of rater biases. IEEE Transactions on Learning Technologies, 14(6), 763-776.

[23] Woods, B., Adamson, D., Miel, S., & Mayfield, E. (2017, August). Formative essay feedback using predictive scoring models. In Proceedings of the 23rd ACM SIGKDD international conference on knowledge discovery and data mining (pp. 2071-2080). https://doi.org/10.1145/3097983.3098160

[24] Wang, Y., Wang, C., Li, R., & Lin, H. (2022). On the Use of BERT for Automated Essay Scoring: Joint Learning of Multi-Scale Essay Representation. arXiv preprint arXiv:2205.03835. https://doi.org/10.48550/arXiv.2205.03835.

[25] Wang, J., Chen, J., Ou, X., Han, Q., & Tang, Z. (2023). Multi-level Feature Fusion for Automated Essay Scoring.

[26] Yang, R., Cao, J., Wen, Z., Wu, Y., & He, X. (2020, November). Enhancing automated essay scoring performance via fine-tuning pre-trained language models with combination of regression and ranking. In Findings of the Association for Computational Linguistics: EMNLP 2020 (pp. 1560-1569). DOI:10.18653/v1/2020.findings-emnlp.141.

# Applications of Missing Data Imputation Methods in Wastewater Treatment Plants

## A Systematic literature Review using the Kitchenham Method

Abdellah Chaoui[1], Kaoutar Rebija[2], Kaoutar Chkaiti[3], Mohammed Laaouan[4],
Rqia Bourziza[5], Karima Sebari[6], Wafae Elkhoumsi[7]

IAV Hassan II, Rabat, Morocco[1, 2, 3, 5, 6, 7]
International Institute for Water and Sanitation, Rabat, Morocco[4]

*Abstract*—Missing data pose a big challenge in the field of wastewater treatment, representing a frequent issue in data quality that can result in misleading analyses and compromised decision-making accuracy. The initial step in data preprocessing involves the estimation and handling of missing values. The primary aim to conduct a comprehensive examination of the existing research concerning missing value imputation in wastewater treatment plants (WWTPs). The focus is specifically on identifying and outlining various imputation techniques employed in this field, while paying close attention to their respective strengths and limitations. To ensure a methodical approach, this study adopts the systematic literature review (SLR) using Kitchenham's guidelines. In order to gather relevant and up-to-date papers, the research leverages the scientific database "Scopus" to retrieve and analyze all pertinent papers during the search process. By doing so, this research aims to contribute valuable insights into the different strategies used for imputing missing values in WWTPs and to shed light on their practical implications and potential drawbacks. Form 599, a total of 16 research papers were selected to assess the review questions. Finally, several recommendations were given to address the limitations identified in the reviewed studies and to contribute to more accurate and reliable data analysis and decision-making in the wastewater treatment domain.

*Keywords—Systematic literature review; kitchenham' method; wastewater treatment; imputation methods; missing data*

## I. INTRODUCTION

The presence of missing values presents a notable obstacle to ensuring the data quality of WWTPs datasets. Despite the presence of well-designed data collection systems in many treatment plants, the attention given to data quality is often inadequate [1].

This problem affects the performance of data analytics, leading to increased bias and decreased accuracy. The presence of missing values can be attributed to various factors, such as events causing measurement failures, holidays, and shifts with less experienced personnel [2]. As a result, gaps or discontinuities arise in the data records, severely hindering the modeling and identification of the process [3].

According to Rubin's [4], missing values can be classified into three main mechanisms, presented below:

- "Missing completely at random" (MCAR): The absence of data has no correlation on the missing data itself.

- "Missing at random" (MAR): Missing values that exhibit a relationship with the observed values.

- "Missing not at random" (MNAR): It applies when neither of the previous mechanisms is valid, and the missing values are typically associated with unobserved predictors or the missing value itself [5].

Over the past, researchers have shown considerable interest in that type of problem. Common approaches for handling missing data include deletion and imputation. Imputing missing data is a crucial step as any data analysis with incomplete datasets would yield invalid conclusions. Ignoring this step can result in biased estimations [6] - [7] While missing data imputation is a well-established technique in data analysis, its application in the context of WWTPs remains relatively unexplored. Existing literature on WWTPs often overlooks or inadequately addresses the critical issue of missing data imputation. Consequently, there is an urgent need to systematically review and evaluate the available missing data imputation methods specifically for WWTP datasets.

There exists an urgent requirement for a dependable and efficient approach to substitute missing data, as this is crucial for accurately assessing the variability of plant influent data. By doing so, more precise design proposals and performance evaluation reports can be generated; leading to improved decision-making processes in wastewater treatment plants [2].

This paper aims to analyse the techniques employed for imputing missing data in WWTPs and review the available methods through imputation. The following sections will present a concise overview of the relevant literature and the quantity of research studies that concentrate on imputing missing data in WWTPs.

In this paper, Section I offers an introduction, Section II outlines the research methodology, and Section III discusses the research findings. A discussion of the results is provided in Section IV, while Section V concludes the article.

## II. RESEARCH AND REVIEW METHOD

In this section, the methodology used is this paper is Kitchenham' method as presented below:

### A. Planning the Review

In this section, the review methodology essential for conducting the systematic literature review (SLR). This entails formulating research questions aligned with the primary objective of the review, devising a robust search strategy, and crafting a comprehensive review protocol. Each of these aspects plays a critical role in ensuring the rigor and effectiveness of the SLR process.

*1) Research questions*: The primary objective of this review is to examine the current literature concerning imputation methods used in the wastewater field. The specific research questions (RQs) are outlined below:

*a)* What are the existing methods applied in wastewater treatment plants?

*b)* How effective are the existing methods in handling missing data challenges?

*c)* What are the limitations of those techniques applied specifically in the context of wastewater treatment plants?

These RQs serve as the guiding framework for this study and facilitate a systematic and thorough analysis of the relevant literature. RQ1 identifies and documents the various techniques used in the context of wastewater treatment plants to handle and optimize missing data imputation. RQ2 focuses on assessing the effectiveness of these existing methods in effectively addressing the challenges posed by missing data in wastewater treatment plants. Lastly, RQ3 aims to analyze the limitations of different missing data imputation techniques specifically within the context of wastewater treatment plants.

*2) Search strategy*: The Scopus database was chosen because of the wide range of academic literature from a variety of fields, including engineering and environmental sciences. It provides a huge selection of peer-reviewed journals, conference papers, and other pertinent literature. The search string used to retrieve articles from the scientific database is described as follows: ("Imputation" OR "missing value*") AND ("Wastewater" OR "WWTP" OR "WATER").

*3) Inclusion and exclusion criteria*: The inclusion and exclusion criteria are illustrated in Table I. By applying these criteria, the aim was to identify and focus on the most pertinent studies that align with the research objectives and ensure the inclusion of high-quality and relevant sources in the final analysis.

*4) Quality criteria*: The primary objective of this section is to check that primary studies contain adequate information to address the research questions. Each criterion is labeled as 'QAC,' which stands for Quality Assessment Criteria. These criteria serve as a means to assess the quality and relevance of each primary study, ensuring that they provide sufficient insights to effectively answer the research questions.

TABLE I.        THE INCLUSION AND EXCLUSION CRITERIA.

| Inclusion criteria | Exclusion criteria |
|---|---|
| Papers that address missing data imputation methods applied in the context of wastewater treatment plants. | Papers that don't address missing data imputation methods applied in the context of wastewater treatment plants |
| Papers published in any journal or conference proceedings and in any language. | Multiple versions of the same study and duplicate publications |
| Articles that are available in full text | Articles that are not available in full text |

These QACs play a vital role in assessing the quality of the selected articles, enabling the determination of their overall quality and suitability for the systematic review.

The quality of studies is assessed through the following evaluation questions:

- **QAC.1** Does the paper use missing data imputation methods for the wastewater domain?

- **QAC.2** Were the key parameters containing missing values mentioned clearly in the paper?

- **QAC.3** Did the researchers explain the performance measurements used?

- **QAC.4** Does the paper cover limitations of the proposed method?

Apart from evaluating the inclusion and exclusion criteria, a thorough examination of each primary study was conducted, employing specific QAC questions [8]. In the evaluation process, each primary study was assigned a score between 0 and 1. A score of 1 indicated that the study fully addressed the QAC question, while a score of 0.5 denoted a partial answer. On the other hand, if the study failed to address the QAC question, a score of 0 was given. The cumulative score for each study was then calculated by summing the scores for all the QAC questions.

Upon completing the quality assessment for each primary study, it was observed that the total score of the selected studies exceeded 50% for each QAC, as presented in Table II.

TABLE II.        QUALITY ASSESSMENT CRITERIA AND RESULTS OF SELECTED ARTICLES

| Criteria | Responding score | Total score |
|---|---|---|
| QAC01 | {0, 0.5, 1}<br>(No, Partially, Yes) | 16 studies (100%) |
| QAC02 | {0, 0.5, 1}<br>(No, Partially, Yes) | 12 studies (75%) |
| QAC03 | {0, 0.5, 1}<br>(No, Partially, Yes) | 13 studies (81.25%) |
| QAC04 | {0, 0.5, 1}<br>(No, Partially, Yes) | 9 studies (56%) |

This finding suggests that the primary studies included in the review contain substantial and relevant information.

## B. Conducting the Review

The search was conducted on April 1st, 2023, without imposing any date or language restrictions. The article selection process involved applying the specified search string, resulting in 599 initial papers. From these papers, relevant information was exported to a spreadsheet, then, the search results were filtered by removing the duplicates articles and those with no abstract available, which left 593 papers. The remaining papers were subjected to a manual review of their titles and abstracts, leading to a selection of 61 papers retrieved from the water quality field, surrounding wastewater treatment. The subsequent step involved referring to and reading the full-text articles in a meticulous manner. During this process, five articles were excluded due to the unavailability of their full text. Then, after analyzing all the papers and organizing the evidence specifically related to wastewater treatment, it was determined that only 16 articles were deemed relevant and shortlisted. As a result, 16 articles successfully met the research questions and satisfied all the inclusion and quality assessment criteria outlined. The paper selection procedures are succinctly summarized in Fig. 1.
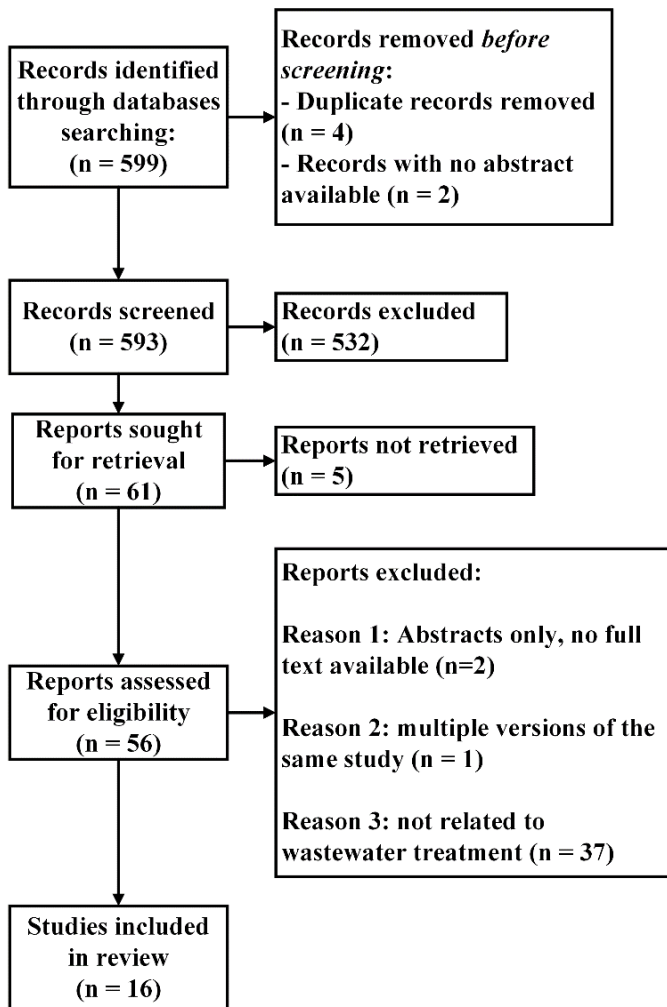


Fig. 1. The article selection process.

## III. FINDINGS

This section presents and analyzes the results obtained from the literature review. Findings are divided into three subsections, with the first one showcasing the various methods used. The second subsection discusses the effectiveness of these existing methods. Finally, the third subsection explores the strengths and limitations of the different methods.

### A. The Identified Methods

This subsection primarily focuses on RQ1, which aims to identify the existing methods. A concise overview of the techniques employed to handle missing values in WWTPs is presented in this subsection. Fig. 2 illustrates the publication trend over time in this specific research area.
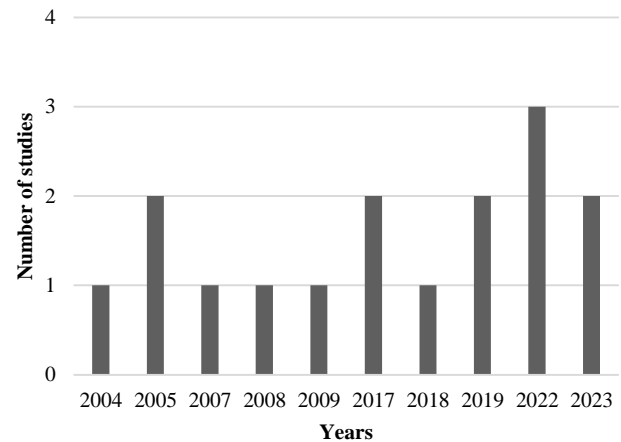


Fig. 2. Number of studies published per year.

In their study, Huo et al. [9] the Two-directional Exponential Smoothing (TES) method to impute missing data in a WWTP. In another study in 2010, they applied also the TES and TESWN (Two-directional Exponential Smoothing with Nearest Observations). The TES method involves generating a hypothetical complete data set using the average of nearest observations (ANO) method. It then forecasts the missing values using an exponential smoothing algorithm in both the forward direction (Forward ES) and the backward direction (Backward ES). The missing data points' ultimate replacement values are obtained by averaging the estimates derived from both the forward and backward exponential smoothing forecasts. The TESWN method shares similarities with the TES approach but includes a white noise term to handle random effects observed in the data, which might not be adequately addressed by the autocorrelation function [10].

Zhang et al. [11] choose the self-organizing map (SOM) model to impute the missing data by training the model using available data and then presenting the depleted vector to the SOM to identify its best matching unit (BMU). The missing variable values are acquired by referring to their respective values in the BMU.

In the study conducted by Villez et al. [12], the imputation of missing values was carried out through a backward calculation based on scores obtained from the inverse Principal Component Analysis (PCA). The scores were

estimated using the single component-projection method [13]. Negative estimates for concentrations were rectified by adjusting them to zero. After this adjustment, any remaining missing variables were subsequently re-estimated using the same methodology.

Borzooei et al. [14] investigates the application of the Cubic Hermite interpolation method for filling in missing values within data. This method is particularly suitable for datasets characterized by rapid and non-linear changes. It employs a third-degree polynomial function to approximate the missing value based on the surrounding data points. To use this method effectively, the data must exhibit continuity, and the function must be differentiable over the relevant interval.

Furthermore, a minimum requirement of having at least two adjacent points to the missing value is necessary for performing the interpolation.

De Mulder et al. [15] employed various filling algorithms to address missing data gaps. These algorithms included interpolation, the utilization of daily average values, and the incorporation of values from the previous day, correlation-based approaches, and the application of the influent model.

Azizoğlu et al. [16] conducted a study, employing six distinct machine learning algorithms, including Linear Regression (LR), Support Vector Machines (SVM), K-Nearest Neighbors (KNN), Random Forest (RF), Decision Tree (DT), and Adaboost, to estimate missing pH data in two distinct datasets.

Phung et al. [17] utilized the multiple imputation procedure to handle missing values. Instead of assigning a single value to each missing data point, they employed Rubin's [4] multiple imputation approach, which replaces each missing value with a set of plausible values. Afterwards, these imputed datasets were analyzed using standard procedures designed for complete data, and the results obtained from these analyses were combined. The process of combining results from different imputed datasets remained consistent, regardless of the specific complete-data analysis method used.

Pascual-Pañach et al. [18] explores the utilization of the Case-Based Reasoning (CBR) approach for online imputation of missing values. This approach addresses the data imputation problem by leveraging past solutions to analogous problems. By employing the Case-Based Reasoning (CBR) principle in data imputation, values from similar historical scenarios are leveraged to replace incorrect or missing values. To improve the effectiveness of the data imputation process, optimal case feature weights are determined using genetic algorithms (GA). The proposed methodology is validated using real data obtained from an operational WWTP process.

Xiao et al. [19] suggested the implementation of Auto-associative Neural Networks (ANN) along with a recursive minimization strategy to address missing values in fault diagnosis for wastewater processes. The ANN is trained using available data to capture the inherent patterns and interrelationships among the variables. Meanwhile, the recursive minimization strategy is employed to iteratively update the missing values based on the learned patterns until convergence is achieved.

Ba-Alawi et al. [20] employed R2AU-Net, an automated data reconciliation and imputation approach tailored to handle missing and faulty data in the membrane bioreactor (MBR) process. This method used a recurrent residual convolutional neural network (CNN) with an attention gate (AG) connection to effectively impute consecutive missing data and reconcile faulty sensors in the MBR process. During training, the model employs backpropagation with the Adam optimizer and mean squared error (MSE) as the activation function. The input and output sizes are set to 18, corresponding to the number of studied sensors. To enhance performance and training speed, the R2AU-Net model incorporates batch normalization (BN) in each R2CL block. The training process is carried out using the Keras library and TensorFlow backend, with 370 epochs and a batch size of 24.

In their research article, Han et al. [21] utilized the univariate imputation method (UIM) in conjunction with the SSD method and SVR model. The UIM decomposes the time series into seasonal, trend, and remainder components and employs specific imputation methods for each component. The SSD method addresses missing values in the seasonal component by identifying repeating patterns. On the other hand, the SVR model is responsible for imputing missing values in the trend and remainder components. By integrating the imputation results, UIM effectively handles missing values in WWTP time series data.

Safford et al. [22] focuses on the application of the EM-MCMC algorithm for estimating missing values in wastewater qPCR data. The proposed method involves a systematic process that begins with the initialization of hyperparameters. Subsequently, Monte Carlo samples of the latent parameters are generated using the Markov Chain Monte Carlo (MCMC) technique. Finally, the maximum likelihood estimates of the hyperparameters are computed based on the sampled latent parameters.

Yan et al. [23] used the Non-Linear Decreasing Inertia Weight Particle Swarm algorithm (NLDIWPSO) based optimal Support Vector Regression (SVR) approach to impute missing values. For abnormal values and missing values with a non-continuous distribution over time, they used the average of non-abnormal data for a period of three days before and after to fill the gaps. Conversely, for abnormal values and missing values with a continuous distribution over time, the NLDIWPSO-based optimal SVR method was employed for forecasting purposes.

Oliveira-Esquerre et al. [24] used linear interpolation for estimating missing values, citing its simplicity [24]. This method was applied with the constraint that it was only employed for a maximum of two consecutive missing values.

In summary, various methodologies have been employed to handle missing data in WWTP studies and there is no imputation technique consistently outperforms every other. The Table III below summaries the missing data imputation methods with their used respective key parameter in a WWTP.

TABLE III.     MISSING DATA IMPUTATION METHODS, KEY PARAMETERS, AND RELEVANT STUDIES

| Missing Data imputation method | Parameter | Studies |
|---|---|---|
| R2AU-Net | - pH,<br>- Dissolved oxygen (DO) | [20] |
| Univariate Imputation Method (UIM)<br>(SSD method & SVR model) | - pH,<br>- SS<br>- BOD<br>- NH4 | [21] |
| Linear regression (LR)<br>K-Nearest Neighbors (KNN)<br>Random Forest (RF)<br>Adaboost<br>Decision Tree (DT)<br>Support Vector Machines (SVM) | - pH | [16] |
| Coupling the Expectation Maximization (EM) algorithm with the Markov Chain Monte Carlo (MCMC) method (EM-MCMC) | - N1<br>- N2<br>- PMMoV concentrations | [22] |
| Case-Based Reasoning (CBR) approach | real data from a WWTP | [18] |
| Cubic Hermite interpolation method | - COD<br>- N-NH4<br>- TSS<br>- T°<br>- Influent flow rate (Qin) | [14] |
| -For abnormal values and missing values that are discontinuously distributed over time: the average of the non-abnormal data for three days before and after was used to fill it.<br><br>-For abnormal values and missing values that are continuously distributed over time: the Non-Linear decreasing inertia weight particle swarm algorithm (NLDIW-PSO) based optimal Support Vector Regression (SVR) was used to forecast. | - PH<br>- COD<br>- BOD5<br>- TP<br>- TN<br>- NH4-N | [23] |
| Interpolation<br>Correlation<br>Daily average<br>Day before<br>Influent model | - CODt<br>- NH4 | [15] |
| Auto-associative neural network (ANN) with a recursive minimization strategy | | [19] |
| Multiple imputation (MI) | - Atenonol<br>- Codeine<br>- Cafeine<br>- Hydrochlorthiazide<br>- Acesulfame<br>- Salicylic Acid<br>- Carbamazepine<br>- Naproxen | [17] |
| SOM | - Ammonia-nitrogen,<br>- Soluble reactive phosphorus (SRP),<br>- SS,<br>- COD<br>- BOD5 | [11] |
| TES and TESWN | - TSS | [10] |
| Kohonen self-organizing map (KSOM), unsupervised neural networks | - flow rate<br>- Influent BOD, and TSS<br>- WAS rate<br>- mixed liquor suspended solids MLSS<br>- return activated sludge mixed liquor suspended solids<br>- stirred sludge volume index SSVI<br>- sludge age<br>- food to microorganism's ratio F/M<br>- effluent flow, BOD, COD and TSS. | [3] |
| PCA projection method | - nitrogen species | [12] |
| Two-directional exponential smoothing (TES) | - BOD5<br>- TSS<br>- NH4-N | [9] |

| | | |
|---|---|---|
| Linear interpolation | - BOD<br>- COD<br>- COL color<br>- COND conductivity<br>- NAM inlet ammonia concentration<br>- NN inlet nitrate concentration<br>- pH<br>- PAP paper production<br>- PULP pulp production<br>- RF rainfall<br>- T°<br>- TSS | [24] |

## B. The Challenges

Existing methods have varying degrees of effectiveness in handling missing data challenges. Ba-Alawi et al. [20] found that the R2AU-Net model exhibited the highest imputation performance for missing data, even when the missing interval increased to 50%. It outperformed conventional methods like PCA and DPCA, as well as neural methods like AE and VAE, with the lowest Mean Absolute Error (MAE) value of 0.31 mg/L. Consequently, the R2AU-Net missing data imputation approach is regarded as highly effective in tackling missing data issues. Additionally, the paper explores the use of the PCA projection method to estimate missing data in the SHARON process. Villez et al. [12] showed that the estimation of missing data related to nitrogen species enhances the performance of a dynamic PCA model. However, despite this improvement, the impact of data gaps remains significant, as the undetected failure ratio nearly doubles when no estimates are employed.

Therefore, while PCA can be helpful in handling missing data challenges, it may not completely solve the problem.

According to the experimental results presented by Han et al. [21], the UIM method, as proposed in the study, proves to be effective in imputing missing data in WWTP time series compared to the other seven competitors examined. In the testing phase, UIM underwent evaluation using six distinct WWTP time series, and the outcomes demonstrated that it strikes a well-balanced trade-off between imputation accuracy and processing time. Notably, UIM and NA.linear exhibit remarkable performance concerning Root Mean Squared Error (RMSE) when confronted with significant intervals of missing data. Moreover, the proposed UIM exhibits the capability to handle a maximum missing ratio of 45%.

Based on Azizoğlu & Ünsal's study in 2022 [16], machine learning algorithms proved to be highly effective in predicting missing pH data. The performance was evaluated using the MAE, mean squared error (MSE), and RMSE as metrics. The results indicated that the SVM (Support Vector Machine) algorithm outperformed other algorithms in all three-performance metrics for both datasets. Consequently, the method of imputing missing data using machine learning algorithms was found to be a successful approach in addressing issues related to missing data.

Pascual-Pañach et al. [18] findings, the performance of the proposed methodology of using a Case-Based Reasoning (CBR) approach was improved by obtaining optimal case feature weights using genetic algorithms (GA). In comparison to non-calibrated CBR imputation systems, the technique was deemed highly effective, as the RMSE of the estimation using weighted features was nearly 40% lower than the non-weighted estimation when employing temporal CBR (TCBR). Moreover, the TCBR approach exhibited even better performance, with an RMSE approximately 60% lower than the calibrated CBR approach.

Yan et al. [23] assessed the performance of the NLDIW-PSO based optimal SVR machine learning model for imputing missing data using the coefficient of determination and Pearson's correlation coefficient. They found that this method achieved the highest prediction accuracy when compared to other data-driven models. Furthermore, the experimental results highlighted several advantages of the proposed model, including enhanced stability and time efficiency compared to traditional data-driven models like BP ANN, Bayesian network model, and Decision Tree model. Consequently, the NLDIW-PSO algorithm demonstrated strong performance in imputing missing data.

According to De Mulder et al. [15], the reliability of different missing data imputation methods was tested for different types of data. The results showed that using the influent model to fill gaps in the data yielded the highest reliability, while linear interpolation was also effective for smaller gaps in the data. However, all filling algorithms seem to do what they were designed for in a satisfying way, and the choice of method may depend on the specific dataset and the purpose of the analysis.

Xiao et al. [19] demonstrated the effectiveness of the current auto-associative neural network (ANN) with a recursive minimization strategy in handling missing data, as well as overcoming the Gaussian assumptions of traditional multivariate statistics models. Through simulation studies, the proposed method showcased good performance, even in scenarios with significant amounts of missing data in both the BSM1 simulation platform and real WWTP datasets.

Zhang et al. [11] concluded that the self-organizing map (SOM) model was an accurate and effective method for predicting missing values and replacing outliers in the integrated constructed wetland (ICW) data set. The SOM model demonstrated resilience to missing values and effectively processed incomplete data sets, resulting in accurate predictions. For ammonia-nitrogen, SRP, COD, SS, and BOD, the proportions of missing values and outliers were approximately 4%, 3%, 41%, 54%, and 61%, respectively. According to Rustum & Adeloye [3], the Kohonen self-organizing map (KSOM) proves to be a valuable tool for

imputing missing values and handling outliers in high-dimensional datasets. The results demonstrate that the KSOM outperforms univariate prediction models based on linear regression and backpropagation ANN. Among the three approaches, the linear regression model displayed the least performance. Evaluation of the KSOM's performance using mean square error (MSE) and average absolute error (AAE) as parameters revealed that the KSOM achieved lower MSE and AAE values compared to regression and ANN. Additionally, a notable advantage of the KSOM is that the same map can be used to predict any missing value in any variable.

Huo et al. [10] showed that the TES and TESWN methods proposed in the article are effective in handling missing data challenges. The TES method is ideal when the objective is to minimize the average error linked to missing values, whereas the TESWN method is more suitable for quantifying the level of uncertainty associated with the missing values. ANO and AVE were utilized as benchmarks to compare the performance of the TES and TESWN methods. In their study, Huo et al. [9] pointed out that several commonly used methods for estimating missing values rely on the assumption of MCAR (missing completely at random), which is not applicable in their data due to the presence of a regular pattern of missing data. To address this challenge, the TES method is presented as a potential solution. The authors employed performance parameters such as R2, RMSE, and Mean Absolute Percent Error (MAPE) to assess the effectiveness of the time series models they developed.

*C. Limitations*

The UIM method proposed in the study can handle missing data up to a maximum ratio of 45%. However, when the missing ratio exceeds 45%, the UIM method may not generate an appropriate result [21].

According to Azizoğlu & Ünsal's [16], linear regression (LR) assumes a linear relationship between the variables and may not work well with non-linear data. K-Nearest Neighbors (KNN) is sensitive to the choice of k value and may not work well with high-dimensional data. Random Forest (RF) and Adaboost may overfit the data if the number of trees is too high. Decision Tree (DT) may suffer from overfitting and instability if the tree is too deep or complex. Support Vector Machines (SVM) can be computationally expensive for large datasets and may not work well with imbalanced data.

For Safford et al. [22], the EM-MCMC method encounters limitations in terms of incomplete comparisons due to sampling zones being added over time, and the need for further testing of the effect of different data groupings on model performance.

The Cubic Hermite interpolation method assumes that the data is smooth and continuous [14]. This technique may not be effective for datasets with a significant number of missing values. It also may not be suitable for datasets with irregular time intervals between observations. The Cubic Hermite interpolation may introduce errors when dealing with data containing outliers or extreme values [14].

Per the findings of De Mulder et al. [15], interpolation operates under the assumption of a linear relationship between

missing data and the surrounding data points. Correlation-based approaches, on the other hand, rely on the presence of a correlation that may not be existent. Daily average estimation may fall short in capturing the full variability of the data, leading to potential biases. Likewise, relying on the previous day's data assumes a level of similarity that may not always be valid. Finally, the use of influent models requires a deep understanding of the underlying system and its intricacies.

Phung et al. [17] found that the fault diagnosis performance using estimated values by the auto-associative neural network (ANN) with a recursive minimization strategy would notably decrease when the percentage of missing values surpasses around 30%. However, if the missing values are not predominant across most variables for each sample simultaneously, the acceptable limit for the percentage of missingness could be slightly higher.

Zhang et al. [11] asserted that the self-organizing map (SOM) method requires a large amount of data to be effective. In a similar vein, Rustum & Adeloye in [3] emphasized that the proposed KSOM need a large amount of data to train the KSOM. Additionally, the KSOM exhibits sensitivity to initial conditions and poses challenges in determining the appropriate number of nodes [3]. SOM method may not work well with categorical or binary data, as it is designed for continuous and numeric variables. Also, the accuracy of the imputed values depends on the quality of the training data and the relationships between variables [25]. It is also proved that the KSOM is not suitable for predicting extreme values that are outside the range of the training data [3].

According to Huo et al. [10], they observed that the TES and TESWN methods depend on time series models, which might not produce satisfactory outcomes when dealing with missing data unrelated to time. Furthermore, the TES method neglects the uncertainty associated with the missing value, resulting in an underestimation of the population variance for both influent data and simulated effluent concentrations. Huo et al. [9] It was stated that the TES method functions based on the assumption that the missing values are missing at random (MAR). Consequently, the accuracy of the imputed values may be influenced by the assumptions made by the method. Additionally, the TES method could erroneously introduce abrupt temporal changes in variables within the data record. In fact, the performance of TES and TESWN methods may be contingent on specific characteristics of the data being imputed, such as the degree of autocorrelation and the presence of outliers [10].

According to the findings of Villez et al. [12], in the missing data imputation technique using PCA, the undetected failure ratio appears to be significantly impacted by the presence of gaps in the data. This ratio nearly doubles when no estimates are employed. This suggests this method may not be able to accurately estimate missing data in all cases, leading to potential limitations in the performance of the model.

In their paper, Oliveira-Esquerre et al. [24] applied linear interpolation to estimate missing values, but they limited it to no more than two consecutive missing values. This indicates that linear interpolation might not be effective for estimating

missing values when there are more than two consecutive missing values. The original database covered a period of 1427 consecutive days, roughly a four-year daily record. However, the significantly high occurrence of missing values for several variables, particularly for TSS, NAM, and NN variables, poses a substantial issue in the dataset. Missing values are more prevalent than available data for these variables.

## IV. DISCUSSION

Findings from this paper reveal that there are only a limited number of articles (16 in total) discussing imputation methods used in WWTPs. This suggests that the literature on this filed is relatively scarce. However, despite the limited number of studies, the findings indicate a diverse range of approaches being explored.

These studies focused on various imputation methods, including the MSF-ARI approach (R2AU-Net) [20], univariate imputation methods (such as the SSD method and SVR model) [21], the SVM algorithm [16], coupling the expectation maximization (EM) algorithm with the Markov Chain Monte Carlo (MCMC) method (EM-MCMC) [22], Case-Based Reasoning (CBR) approach [18], Cubic Hermite interpolation method [14], Non-Linear decreasing inertia weight particle swarm algorithm (NLDIW-PSO) based optimal Support Vector Regression (SVR) [23], Daily average, auto-associative neural network (ANN) with a recursive minimization strategy [19], Multiple imputation (MI) [17], Linear interpolation [24], Two-directional exponential smoothing (TES) [9], PCA projection method [12], Kohonen self-organizing map (KSOM) [3], TES and TESWN [10].

The effectiveness of these imputation methods in handling missing data challenges was evaluated based on several criteria, including imputation accuracy, computational efficiency, robustness to different types and patterns of missing data [9][10]. The results varied across the studies, with some methods demonstrating high accuracy in imputing missing values [16][18][23], while others showed limitations in certain aspects [3] [11] [12] [14] [22].

Several limitations were identified across the reviewed papers. One common limitation was the lack of generalizability of proposed approaches to different WWTPs with varying configurations and operating conditions. In some cases, the proposed methods required a substantial amount of training data [3] [11], which may not be available in all WWTPs. Another limitation was the failure to consider sensor drift, which could impact the accuracy of imputed data. Furthermore, many studies did not compare their proposed methods with other state-of-the-art imputation techniques or evaluate their performance on diverse datasets. The generalizability of findings was often limited by the use of data from a single WWTP or a specific location [3] [9] [24], raising concerns about the applicability of the proposed methodologies to other systems.

Future research should address these limitations by conducting broader investigations, comparing with existing methods, and exploring the impact of various factors on data

imputation in WWTPs to bridge the existing knowledge gaps and ensure the reliable management and analysis of data in this domain.

## V. CONCLUSION

In this study, the SLR examine the existing missing data imputation methods used in WWTPs. This SLR is also concerned with aiding researchers working in this field in the decision-making processes and enhancing the performance of WWTPs. This study concentrated on the scientific database Scopus.

The findings from the selected studies reveal a limited number of articles discussing this specific topic with only 16 articles meeting the inclusion criteria. Despite the scarcity of literature, the findings demonstrate a diverse range of approaches being explored in this field.

The studies indicate that these imputation methods have shown promising results in handling missing data in various aspects of WWTPs, including influent data and water quality data. They have been employed to impute missing values for different variables, such as flow, temperature, BOD5, suspended solids, ammonia nitrogen, pH values, and more. The effectiveness of these methods has been evaluated using different evaluation metrics, such as mean squared error (MSE), MAE, and coefficient of determination ($R^2$).

However, it is important to acknowledge some limitations identified in the reviewed studies. These include the lack of generalizability of proposed approaches to different WWTPs with varying configurations and operating conditions, the requirement for a substantial amount of training data which may not be universally available, the failure to consider sensor drift in imputation methods and the need for comparing the proposed methods with other state-of-the-art techniques are also areas that require attention.

Based on these findings, several recommendations can be made. Further investigation is warranted, specifically taking into account the missing mechanisms and rates associated with data gaps in this particular field. Furthermore, researchers should aim to validate and generalize the proposed imputation methods by conducting experiments in multiple WWTPs with diverse characteristics. This will enhance the understanding of their performance and applicability in different settings. Moreover, additional evaluation metrics such as RMSE and MAE should be employed to comprehensively assess the effectiveness of the imputation methods. Comparative studies, benchmarking the proposed methods against other state-of-the-art techniques, would also provide valuable insights into their relative strengths and weaknesses.

## REFERENCES

[1] C. Rosen, "Monitoring wastewater treatment system.," thesis, Dept. of Industrial Electrical Engineering and Automation, Lund Institute of Technology, Lund Univ., Lund, Sweden., 1998.

[2] J. Huo, C. Cox, W. Seaver, B. Robinson, and Y. Jiang, "Innovative missing data replacement methods using time series models," in World Environmental and Water Resources Congress 2008: Ahupua'a - Proceedings of the World Environmental and Water Resources Congress 2008, 2008. doi: 10.1061/40976(316)670.

[3]  R. Rustum and A. J. Adeloye, "Replacing outliers and missing values from activated sludge data using kohonen self-organizing map," Journal of Environmental Engineering, vol. 133, no. 9, pp. 909–916, 2007, doi: 10.1061/(ASCE)0733-9372(2007)133:9(909).

[4]  D. B. Rubin, "Inference and missing data," Biometrika, vol. 63, no. 3, pp. 581–592, Dec. 1976, doi: 10.1093/BIOMET/63.3.581.

[5]  B. L. Ford, "An overview of hot-deck procedures," Incomplete Data Sample Surveys, vol. 2, 1983.

[6]  N. Z. Zainal Abidin, A. R. Ismail, and N. A. Emran, "Performance Analysis of Machine Learning Algorithms for Missing Value Imputation," Int. J. Adv. Comput. Sci. Appl., vol. 9, no. 6, 2018.

[7]  L. Bargelloni et al., "Data imputation and machine learning improve association analysis and genomic prediction for resistance to fish photobacteriosis in the gilthead sea bream," Aquac. Reports, vol. 20, pp. 100–661, 2021.

[8]  L. Yang et al., "Quality Assessment in Systematic Literature Reviews: A Software Engineering Perspective," Inf Softw Technol, vol. 130, p. 106397, Feb. 2021, doi: 10.1016/J.INFSOF.2020.106397.

[9]  J. Huo, W. L. Seaver, R. B. Robinson, and C. D. Cox, "Application of Time Series Models to Analyze and Forecast the Influent Components of Wastewater Treatment Plants (WWTPs)," World Water Congress 2005: Impacts of Global Climate Change - Proceedings of the 2005 World Water and Environmental Resources Congress, pp. 1–11, 2005, doi: 10.1061/40792(173)97.

[10] J. Huo, C. D. Cox, W. L. Seaver, R. B. Robinson, and Y. Jiang, "Application of two-directional time series models to replace missing data," Journal of Environmental Engineering, vol. 136, no. 4, pp. 435–443, 2010, doi: 10.1061/(ASCE)EE.1943-7870.0000171.

[11] L. Zhang, M. Scholz, A. Mustafa, and R. Harrington, "Application of the self-organizing map as a prediction tool for an integrated constructed wetland agroecosystem treating agricultural runoff," Bioresour Technol, vol. 100, no. 2, pp. 559–565, Jan. 2009, doi: 10.1016/J.BIORTECH.2008.06.042.

[12] K. Villez, C. Rosen, V. H. Stijn, C. K. Yoo, and P. A. Vanrolleghem, "On-line dynamic monitoring of the SHARON process for sustainable nitrogen removal from wastewater," Computer Aided Chemical Engineering, vol. 20, no. C, pp. 1297–1302, Jan. 2005, doi: 10.1016/S1570-7946(05)80058-6.

[13] P. R. C. P. A. T. and J. F. M. Nelson, "Missing methods in PCA and PLS: Score calculations with incomplete observations," Chem. Intell. Lab. Syst., vol. 35, p. 45, 1996.

[14] S. Borzooei, G. H. B. Miranda, R. Teegavarapu, G. Scibilia, L. Meucci, and M. C. Zanetti, "Assessment of weather-based influent scenarios for a WWTP: Application of a pattern recognition technique," J Environ Manage, vol. 242, pp. 450–456, Jul. 2019, doi: 10.1016/J.JENVMAN.2019.04.083.

[15] C. De Mulder, T. Flameling, S. Weijers, Y. Amerlinck, and I. Nopens, "An open software package for data reconciliation and gap filling in preparation of Water and Resource Recovery Facility Modeling," Environmental Modelling & Software, vol. 107, pp. 186–198, Sep. 2018, doi: 10.1016/J.ENVSOFT.2018.05.015.

[16] F. Azizoğlu and E. Ünsal, "Kayıp IoT Verilerinin Makine Öğrenmesi Teknikleri ile Tahmini," El-Cezeri, vol. 9, no. 4, pp. 1388–1397, Dec. 2022, doi: 10.31202/ECJSE.1135485.

[17] D. Phung et al., "Can wastewater-based epidemiology be used to evaluate the health impact of temperature? – An exploratory study in an Australian population," Environ Res, vol. 156, pp. 113–119, Jul. 2017, doi: 10.1016/J.ENVRES.2017.03.023.

[18] J. Pascual-Pañach, M. Sànchez-Marrè, and M. À. Cugueró-Escofet, "Optimizing Online Time-Series Data Imputation Through Case-Based Reasoning," Frontiers in Artificial Intelligence and Applications, vol. 356, pp. 87–90, Oct. 2022, doi: 10.3233/FAIA220320.

[19] H. Xiao, D. Huang, Y. Pan, Y. Liu, and K. Song, "Fault diagnosis and prognosis of wastewater processes with incomplete data by the auto-associative neural networks and ARMA model," Chemometrics and Intelligent Laboratory Systems, vol. 161, pp. 96–107, Feb. 2017, doi: 10.1016/J.CHEMOLAB.2016.12.009.

[20] A. H. Ba-Alawi, K. J. Nam, S. K. Heo, T. Y. Woo, H. Aamer, and C. K. Yoo, "Explainable multisensor fusion-based automatic reconciliation and imputation of faulty and missing data in membrane bioreactor plants for fouling alleviation and energy saving," Chemical Engineering Journal, vol. 452, p. 139220, Jan. 2023, doi: 10.1016/J.CEJ.2022.139220.

[21] H. Han, M. Sun, H. Han, X. Wu, and J. Qiao, "Univariate imputation method for recovering missing data in wastewater treatment process," Chin J Chem Eng, vol. 53, pp. 201–210, Jan. 2023, doi: 10.1016/J.CJCHE.2022.01.033.

[22] H. Safford et al., "Wastewater-Based Epidemiology for COVID-19: Handling qPCR Nondetects and Comparing Spatially Granular Wastewater and Clinical Data Trends," ACS ES and T Water, vol. 2, no. 11, pp. 2114–2124, Nov. 2022, doi: 10.1021/ACSESTWATER.2C00053/SUPPL_FILE/EW2C00053_SI_005.XLSX.

[23] J. Yan, X. Chen, and Y. Yu, "A Data Cleaning Framework for Water Quality Based on NLDIW-PSO Based Optimal SVR," Proceedings - 2018 IEEE/WIC/ACM International Conference on Web Intelligence, WI 2018, pp. 336–341, Jan. 2019, doi: 10.1109/WI.2018.00-71.

[24] K. P. Oliveira-Esquerre, D. E. Seborg, R. E. Bruns, and M. Mori, "Application of steady-state and dynamic modeling for the prediction of the BOD of an aerated lagoon at a pulp and paper mill: Part I. Linear approaches," Chemical Engineering Journal, vol. 104, no. 1–3, pp. 73–81, Nov. 2004, doi: 10.1016/J.CEJ.2004.05.011.

[25] L. Zhang, M. Scholz, A. Mustafa, and R. Harrington, "Application of the self-organizing map as a prediction tool for an integrated constructed wetland agroecosystem treating agricultural runoff," Bioresour Technol, vol. 100, no. 2, pp. 559–565, 2009, doi: 10.1016/j.biortech.2008.06.042.

# Using Ensemble Learning and Advanced Data Mining Techniques to Improve the Diagnosis of Chronic Kidney Disease

Muneer Majid[1]*, Yonis Gulzar[2]*, Shahnawaz Ayoub[3], Farhana Khan[4],
Faheem Ahmad Reegu[5], Mohammad Shuaib Mir[6], Wassim Jaziri[7], Arjumand Bano Soomro[8]

Glocal School of Science and Technology Glocal University, Delhi-Yamunotri Marg (State Highway 57),
Mirzapur Pole, Dist - Saharanpur, U.P. - 247121, India[1, 3, 4]
Department of Management Information Systems, College of Business Administration, King Faisal University,
Al-Ahsa 31982, Saudi Arabia[2, 6, 7, 8]
College of Computer Science and Information Technology, Jazan University, Jazan 45142, Saudi Arabia[5]
Department of Software Engineering, Faculty of Engineering and Technology, University of Sindh, Sindh, Pakistan[8]

*Abstract*—Kidney failure is a condition with far-reaching, potentially life-threatening consequences on the human body. Leveraging the power of machine learning and data mining, this research focuses on precise disease prediction to equip decision-makers with critical data-driven insights. The accuracy of classification systems hinges on the dataset's inherent characteristics, prompting the application of feature selection techniques to streamline algorithm models and optimize classification precision. Various classification methodologies, including K-Nearest Neighbor, J48, Artificial Neural Network (ANN), Naive Bayes, and Support Vector Machine, are employed to detect chronic renal disease. A predictive framework is devised, blending ensemble methods with feature selection strategies to forecast chronic kidney disease. Specifically, the predictive model for chronic kidney disease is meticulously constructed through the fusion of an information gain-based feature evaluator and a ranker search mechanism, fortified by the wrapper subset evaluator and the best first algorithm. J48, in tandem with the Info Gain Attribute Evaluator and ranker search system, exhibits a remarkable accuracy rate of 97.77%. The Artificial Neural Network (ANN), coupled with the Wrapper Subset Evaluator and the highly effective Best First search strategy, yields precise results at a rate of 97.78%. Similarly, the Naive Bayes model, when integrated with the Wrapper Subset Evaluator (WSE) and the Best First search engine, demonstrates exceptional performance, achieving an accuracy rate of 97%. Furthermore, the Support Vector Machine algorithm achieves a notable accuracy rate of 97.12% when utilizing the Info Gain Attribute Evaluator. The K-Nearest Neighbor Classifier, in conjunction with the Wrapper Subset Evaluator, emerges as the most accurate among the foundational classifiers, boasting an impressive prediction accuracy of 98%. A second model is introduced, incorporating five diverse classifiers operating through a voting mechanism to form an ensemble model. Investigative findings highlight the efficacy of the proposed ensemble model, which attains a precision rate of 98.85%, as compared to individual base classifiers. This research underscores the potential of combining feature selection and ensemble techniques to significantly enhance the precision and accuracy of chronic kidney disease prediction.

*Keywords*—*Kidney; chronic kidney disease; support vector machine; k-nearest neighbors; artificial neural network; decision tree*

## I. INTRODUCTION

Large datasets can be mined for significant insights via data mining, which is seen as a necessary stage in the learning process. Its uses are widespread across various industries, including business, healthcare, education, science, government, etc. Data mining is frequently used in the medical sector to forecast diseases [1]. Developing efficient approaches for illness analysis, prediction, and detection is central to this critical area of research in the healthcare industry [2, 3]. Applications for data mining are frequently used in patient care systems, health information systems, and healthcare management and they significantly affect the analysis of disease survival [4, 5].

Data mining and classification approaches are essential for classifying, identifying, analyzing, and predicting disease datasets in the healthcare domain [6,7]. Medical datasets undergo comprehensive type, meticulous research, precise detection, and informed prediction through various classification methodologies. These encompass the sophisticated realm of Artificial Neural Networks (ANN), the discerning approach of K-Nearest Neighbors (KNN), the probabilistic insight of Naïve Bayes, the strategic branching of Decision Tress (J48, C4.5), the adept maneuvering of Support Vector Machines (SVM) etc.

The feature selection approach is crucial in data mining and machine learning as it plays a vital role in knowledge discovery, pattern identification, and statistical sciences [7]. Eliminating pointless attributes from the dataset is the primary goal of feature selection [8]. The refinement of classifier performance accuracy can be achieved by strategically removing specific details. Wrapper and filter approaches can classify feature selection techniques [9, 10].

Machine learning methods called ensembles combine predictions from various classifiers to increase prediction

*Corresponding Author
email: ygulzar@kfu.edu.sa, muneerbazaz@gmail.com

accuracy. An essential process for creating extremely accurate prediction models is the ensemble model. Ensemble models, such as random forest, bagging, boosting, stacking, and voting, are commonly employed in machine learning, data mining, and data science.

Chronic renal failure (CRF), another name for chronic kidney disease (CKD), is a severe and developing health problem worldwide. CKD is characterized by a slow decline in kidney function that impairs the functionality of the renal organs [4]. Due to the lack of apparent symptoms in the early stages, the start of renal failure may initially go unreported [6]. However, the effects of renal failure can seriously harm a person's general health and potentially have deadly implications.

According to the Global Burden of Disease Project, chronic kidney disease (CKD) has recently become a rapidly expanding global health concern. According to statistical statistics, the death rate for people with CKD increased significantly by 90% between 1990 and 2013 [7]. Presently, (CKD) stands as the thirteenth most prevalent contributor to mortality on a global scale. Moreover, CKD prominently ranks within the upper echelon of the five leading causes of death worldwide, as substantiated by findings from the esteemed research conducted by Kidney International [8]. According to the National Kidney Foundation, CKD affects around 10% of the world's population and causes millions yearly deaths [11]. The high mortality rates linked to CKD result from a lack of efficient treatments and a poor understanding of renal disease.

In developing nations, some kidney patients sometimes wait until their ailment has advanced before seeking treatment. This pattern helps explain why CKD is becoming more common [8]. However, detecting the illness at an early stage or during its start can decrease or even stop the occurrence of CKD. Early detection and management of kidney illness can be aided by diagnostic procedures such as blood testing, urine tests, kidney scans, and doctor consultations regarding additional symptoms of kidney disease.

By using feature selection strategies to lower the dimensionality of the features and ensemble models, which include various classifiers, this work focuses on evaluating the accuracy of the methods.

The remainder of this study is divided into the following sections: A literature review is presented in Section II, the techniques are described in Section III, the experimental test findings are shown in Section IV with a discussion that follows and the research is concluded in Section V.

## II. LITERATURE REVIEW

Classification methodologies, the process of selecting relevant features, and the utilization of ensemble approaches stand as foundational pillars within the realms of machine learning and data analysis. Several research endeavors have been undertaken to employ these methodologies to classify disease datasets within the medical domain, and these endeavors have been extensively examined in the discipline. Numerous research studies have shown promising classification accuracy when using feature selection approaches, ensemble models, data mining and machine learning techniques to analyze medical datasets.

A study on the diagnosis of chronic renal illness using Support Vector Machines (SVM) and efficient feature selection techniques was carried out by Polat et al. [6]. To reduce dimensionality, they employed both wrapper and filter feature selection approaches. The study revealed that using Support Vector Machines (SVM) without feature selection led to an impressive accuracy of 97.75% in their analysis. By integrating SVM with a classifier subset evaluator and applying a greedy stepwise technique, the accuracy was enhanced to 98%. Similarly, utilizing Support Vector Machines (SVM) with a wrapper subset evaluator and leveraging a best-first search technique resulted in an elevated accuracy of 98.25%. Correspondingly, merging Support Vector Machines (SVM) with a classifier subset evaluator and applying a greedy stepwise method yielded an accuracy rate of 98.25%. Lastly, employing the best-first search strategy alongside SVM using the filter subset evaluator achieved the highest accuracy rate of 98.5%.

To predict cardiac disease, Bashir et al. [12] suggested an ensemble classifier based on a majority vote framework. The ensemble model was built using Nave Bayes, decision trees based on Gini Index and information Gain, memory-based learners, and Support Vector Machine (SVM), five heterogeneous classifiers. Their MV5 framework obtained an accuracy of 88.5% through trials utilizing stratified cross-validation, with a sensitivity of 86.96%, specificity of 90.83%, and an F-Measure of 88.85. The ensemble model's average accuracy increased compared to the individual base classifiers. The suggested method involved producing personal classifier judgments, successfully integrated to create the new combined model.

Bashir et al. [13] presented the HMV framework for medical decision support, which employs a multi-layer classifier for disease prediction. Their strategy focuses on assembling diverse classifiers into an ensemble model most effectively. Within their system's framework, an array of discerning classifiers is harnessed, including but not limited to Naive Bayes, Linear Regression, Quadratic Discriminant Analysis, K-Nearest Neighbors (KNN), Support Vector Machine (SVM), as well as Decision Trees meticulously constructed using both the Gini Index and the Information Gain criterion. Their HMV ensemble framework outperformed other prediction models in experiments, according to the results. The three components of the HMV framework are data collection and preprocessing, predicting unidentified class labels for test instances, and assessing the suggested HMV ensemble model. They attained the maximum disease categorization and prediction accuracy level using the HMV ensemble model on the chosen dataset.

Data mining techniques were used in a study by Khajehali et al. [14] to uncover parameters impacting pneumonia patients. They suggested a modeling strategy that included ensemble approaches for feature selection and classification with preprocessing, dimensionality reduction and unstructured data classification. They used the Bayesian Boosting method to build a model that identifies variables related to patient length of stay (LOS) in the hospital. The design of their

investigation included various preprocessing stages. SVM and ensemble approach like AdaBoost, Vote, Stacking, and Bayesian Boosting were used in the modelling process. Using a 10-fold cross-validation procedure, Bayesian Boosting, one of these classifier algorithms, was used for data analysis. Ten subsets were created from the dataset, with the training subset being chosen iteratively ten times. The training ensembles encompassed a comprehensive selection, incorporating nine available ten subsets. The findings demonstrated the efficiency of the Bayesian Boosting ensemble technique in forecasting pneumonia disease and anticipating length of stay, with a greater accuracy of 97.17%.

Pritom et al. [15] conducted an extensive investigation into the forecasting of breast cancer recurrence, leveraging a suite of sophisticated classification algorithms, including SVM, Decision Trees, Naive Bayes, and the venerable C4.5 method. Through the use of efficient feature selection techniques, they hoped to increase the accuracy of each classifier. They employed the Info Gain characteristic with a ranker search engine as one such technique. The effectiveness of recurrence prediction was assessed by applying these algorithms on the Weka tool. Upon the unaltered dataset, void of any feature selection, the results unveiled a landscape where SVM distinguished itself with a remarkable precision of 75.75%. Meanwhile, the J48 secured an impressive 73.73% accuracy, while the Naïve Bayes classifier demonstrated notable proficiency, attaining a respectable accuracy of 67.17%. However, after properly implementing feature selection, SVM, C4.5, and Nave Bayes showed improvements of 1.52%, 2.52%, and 9.09%, respectively. This compelling evidence underscores feature selection's remarkable efficacy in elevating the classifiers' accuracy, validating its pivotal role in enhancing performance.

Dulhare et al. [7] constructed classification models to predict and categorize individuals with chronic kidney disease (CKD) using feature selection and the naive Bayes classifier. They used a feature selection technique known as the one R attribute selector to extract useful rules. The model's classification accuracy was evaluated using the best first search engine and the wrapper subset evaluator. Upon assimilating these methodologies into the Weka tool, the Naïve Bayes classifier achieved a notable accuracy threshold of 97.5%, accentuating the profound impact of their integration. This indicates how well the feature selection and classification strategy correctly identifies patients with and without CKD.

Artificial intelligence (AI) and deep learning have revolutionized various industries, including agriculture [16–23], education [24, 25], finance [26], healthcare [27–29] and other domains [30, 31]. In the field of healthcare, AI has shown tremendous promise in improving patient outcomes, enhancing diagnostics, and streamlining healthcare processes. With the ability to analyze vast amounts of data and identify complex patterns, AI-powered systems have opened new frontiers for early disease detection, personalized treatment plans [32], and overall healthcare efficiency. In healthcare, one of the areas where AI and deep learning have made significant advancements is in the early detection of diseases, including cancer [33]. Detecting cancer at an early stage is

crucial for improving treatment success and patient survival rates. Kidney cancer, for example, often presents with few symptoms in its early stages, making early detection challenging. However, deep learning algorithms have proven to be effective in analyzing medical imaging data, such as CT scans and MRI images, to detect kidney tumors at their nascent stages [34].

## III. DIFFERENT TECHNIQUES EMPLOYED IN THE REALM OF CKD

### A. Artificial Neural Network (ANN)

The functioning of natural neurons served as the inspiration for artificial neural network (ANN), often known as a "neural network," which is widely used in practical applications. With changeable weights assigned to each link, it consists of interconnected nodes of artificial neurons, allowing for changes in their spatial layout during information transmission [4]. Being a learning algorithm, ANN can change its structure as it learns by taking in information from its internal and external environments [6]. The network has several layers for message propagation, including an input layer, hidden layers, and an output layer. One or more levels with different numbers of nodes may be included in the hidden layers. These layers are connected, and each node is tied to a certain weight. With ANN, input data is sent to the network to generate predictions while the network learns under supervision. A perceptron, which is the main working component of ANN, may divide datasets into two types. A perceptron is made up of a single node with corresponding weights. Its three key components are the connections between nodes, an adder for adding inputs, and activation functions that control the output.

### B. K-Nearest Neighbor (KNN)

KNN is a nonparametric supervised learning technique that works well with both linear and nonlinear data [1]. It features a rapid training procedure and works especially well for big datasets. KNN determines the k objects that are closest to the place of interest or by majority voting. The selection of items hinges upon identifying the nearest class object, as determined by the minimal distance between the querying instance and the corresponding training example. According to Boukenze, et al. [4], KNN is the algorithm with the quickest model-building execution time. KNN considers k instances—x1, x2…—to forecast the class of a query Xn. Different distance metrics, such as the Euclidean, Manhattan, Minkowski, and Hamming distances, are used to determine which class is closest. This is how the distance formula is put together.

$$\text{Euclidean} = \sqrt{\sum_{i=1}^{n}(Xi - Yi)2}$$

$$\text{Manhattan} = \sum_{i=1}^{n} |Xi - Yi|$$

$$\text{Minkowski} = \sum_{k} (|Xi - Yi|)^q )^{\frac{1}{q}}$$

### C. Decision Tree (J48)

The Weka platform's C4.5 decision tree technique is implemented in Java as a J48 decision tree. It is a development of Ross Quinlan's original ID3 algorithm.

The top-down greedy search method is used by the J48 classification algorithm to build the tree. The final decision tree produced by J48 is made up of sorted branches, where the internal characteristics reflect potential outcomes based on the branching features and the leaf nodes represent the final class results. The separation between information gain and the splitting qualities is the foundation for the tree's creation. Data disorder and uncertainty are measured using entropy. The formula below can be used to determine the entropy of a random variable given a probability "p" and sample "S".

$$\text{Entropy(S)} = \sum_{i=1}^{n} (-pi\ log2(p_i))$$

The most informative aspect for choosing the best node in a decision tree is measured according to information gain. It measures the amount of entropy or uncertainty that is reduced due to dividing the data based on a particular attribute. We take into account the values of the attribute as "v" and the subset of sample "S" that corresponds to each value to determine the information gain for a given attribute "A" about a sample "S". Following are the steps for computing the information gain.

$$\text{Gain (S, A)} = \text{Entropy(S)} - \sum_{v \in \mathbf{Value}}^{\mathbf{n}} (\text{Entropy(Sv)} \frac{|Sv|}{|S|})$$

### D. SVM: Support Vector Machine

One of the quintessential techniques in machine learning, renowned for its prowess in supervised learning, is the Support Vector Machine (SVM) [6]. It is famous for its high-performance abilities in classification, regression, analysis, and prediction tasks on datasets. In the feature space of the training data, SVM creates a distinct hyperplane that divides and categorizes the data points according to their positions about the hyperplane. In data mining, it is frequently used for problems involving regression and classification [1]. When compared to other classification algorithms, SVM, a widely used supervised learning technique, can produce accurate results. SVM strategically endeavors to minimize classification error by optimizing the margin between instances belonging to distinct classes, thereby culminating in an exceptional power. SVM uses the "kernel trick" to determine the separation between a data point and the hyperplane in a modified feature space without explicitly modifying the original features, which is one of its benefits.

### E. Simple Bayes

A classification technique that applies the Bayes theorem under the feature independence presumption is known as the Naive Bayes classifier. It is a probabilistic technique that is frequently used in supervised classification issues in practical settings [1]. Naive Bayes has quick learning skills and works well in applications like diagnosis and prediction. The Nave Bayes algorithm works well with less training data, making it appropriate for classification jobs where data availability is constrained [35, 36]. Each record is predicted and associated with a particular class using the Naive Bayes classification algorithm, which calculates the likelihood that the record belongs to the target class. The most likely class is the one with the highest likelihood.

$$P(P/X) = \frac{P(P/X).P(Y)}{P(X)}$$

## IV. Approach and Empirical Findings

The provided study revolves around two methodologies. The initial approach involves crafting a predictive model through the implementation of several feature curation tactics. The subsequent technique involves establishing a predictive model by harnessing an amalgamation of diverse classifiers.

### A. Techniques for Choosing Features

A comprehensive classification model may be created by removing superfluous features from the data set and reducing the dimensionality of the feature. In this study investigators used the ranker search strategy with the Info Gain Attribute Evaluator feature selection technique to find the most relevant features. The Info Attribute Evaluator operates on a distinctive principle, evaluating an attribute's significance by comparing its information gain with respect to the classes. Moreover, it exhibits remarkable capability in appraising binary numeric attributes, eliminating the need for conventional feature discretization procedures. Moreover, the absent data could be distributed among alternative values based on their averages and commonly appearing values for a definite trait or a numeric feature. Alternatively, it might be considered as a distinct entity. The Attribute Evaluator for Information Gain showcases impressive adaptability, capable of identifying absent data and a range of attribute categories like nominal, temporal, numerical, unary, binary, and vacant minor attributes.

The ranker search technique can be exploited to obtain the rankings of attributes also evaluates each attribute by its specific evaluator in addition to attribute evaluators like information gain and Gini index. It possesses the capability to produce feature prioritization.

In this investigation, a supplementary layer of feature selection was implemented through the synergistic incorporation of a Wrapper Subset Evaluator, seamlessly melded with the precision-driven best first search methodology. This evaluative framework operates by leveraging sophisticated learning pattern to gauge the efficacy of attributes sets, fortified by a meticulous cross-validation process to affirm the soundness of the acquired insights. The detected attributes compass a wide array of characteristics, which consist of text, null nominal, undefined entries, time-related, relational, numeric, individual, paired, and categorical features. Furthermore, its discerning capabilities extend to the identification of attributes within Nominal, Binary, Date and Numeric classes, as well as the nuanced recognition of values within the Missing class domain.

In order to search the space of attribute subsets, first-best search makes use of a greedy hill climbing capacity supplemented with a backtracking capability. The maximum allowed number of consecutive non-improving nodes determines how much backtracking is allowed. The Best first search methodology offers a gamut of strategic pathways for exploration. It may embark upon its journey with an initial attributes set that is void, then propel forward, or alternatively, commence with a comprehensive set and elegantly traverse backward. Furthermore, it possesses the flexibility to initiate from any vantage point, seamlessly navigating in both forward and reverse directions. This dynamic approach encompasses the meticulous consideration of all possible single attribute

augmentation and eliminations at specific junctures and these modalities can be ingeniously combined to forge a tailored exploration strategy.

### B. Ensemble Classifiers

The ensemble with the most heterogeneous classifier typically has the highest accuracy rate. Ensemble learning, a technique in the field of machine learning, revolves around creating multiple prediction models and blending their outputs to enhance the overall performance metrics of each algorithm. Employing an ensemble classifier is the optimal approach for rectifying errors that may arise from the underlying primary classifier [13]. In machine learning combination classification, it is currently increasingly usual to use many classifiers rather than just one. The advantage is that we can use two or more powerful categorization algorithms rather than just one. Hence, the resultant model will reach an elevated echelon of effectiveness and sophistication, equipping it to expertly discern and classify samples gathered from the training, cross-fold validation, and thoroughly examined testing datasets.

The ensemble classification model combines a number of classifiers, each of which affects the outcome in a unique way. These methodologies have ushered in a transformative evolution within the training process, molding classifier models that yield diverse categorization outcomes with unparalleled precision [12]. Ensemble methods' key advantage is that they combine individual classifier rules to provide predictions that are more accurate than those made by those rules alone. To improve prediction accuracy, the ensemble model approach mixes various individual classifiers.

The architecture of the proposed ensemble model is shown in Fig. 1. The proposed system's general methodology uses data from the UCI machine learning repository. For nominal and numeric variables within the dataset, any instances of missing values are meticulously imputed through the modal and mean values derived from the training data. Concurrent with this, the intricacy of features is finely tuned through the skilled utilization of feature selection methods. After feature reduction, we have the optimum feature subset, and the dataset was trimmed down for the proposed research. The reduced subset dataset consists of a few pertinent features. Following a rigorous process of individual attribute value feature selection, the foundational classifier was enriched with a cadre of prominent base classifiers, comprising K-Nearest Neighbors (KNN), J48 decision trees, Artificial Neural Networks (ANN), Naïve Bayes (NB) and Support Vector Machines (SVM). The data has been split into training and test sets. A training set of data was used to train the base classifier, a testing framework for evaluating and predicting illnesses. To improve the results, create a final forecast after combining the classifier using the ensemble voting method. The models' effectiveness is evaluated. Before this, the results were evaluated using ROC, F-Measure, recall, accuracy, and precision. The broad suggested system design is demonstrated in Fig. 1.
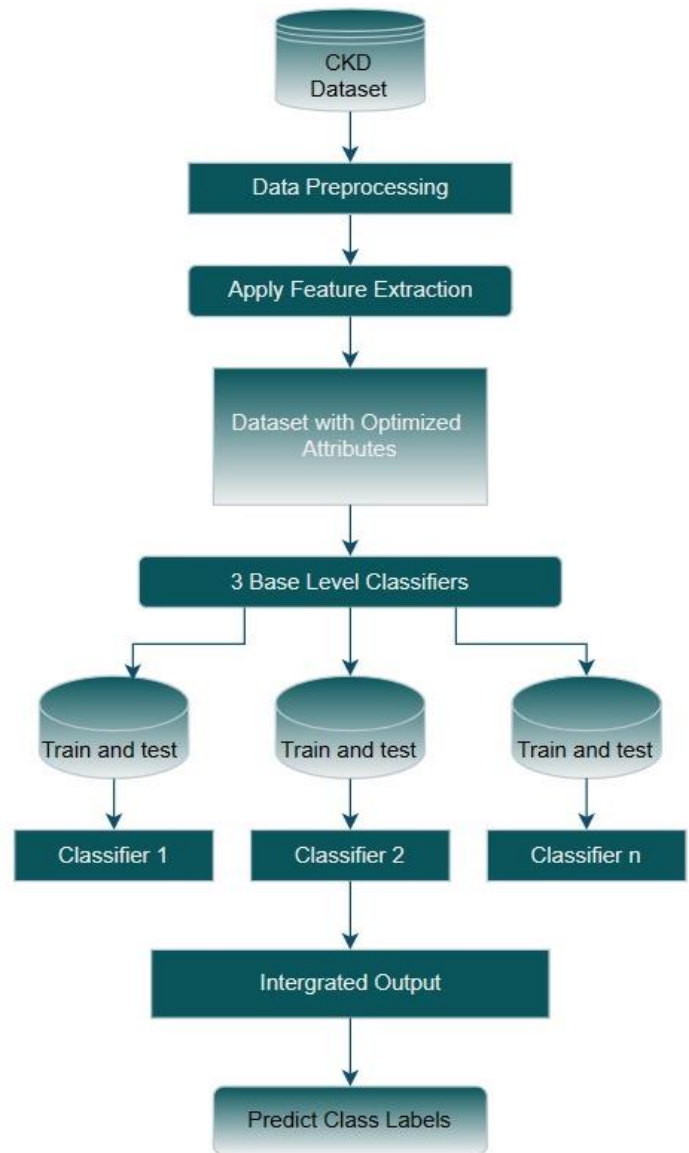


Fig. 1. The architecture of proposed ensemble model.

### C. Dataset Exploited

The dataset from the UCI machine learning repository was acquired [11]. The collection contains 400 examples with 24 attribute values and 1 class attribute. These traits are included in the Table I below. The dataset contains 400 samples, 250 of which have CKD and 150 have not. It has the following characteristics: (14 numeric, 11 nominal) 24 + class = 25.

### D. Various Performance Indicators Explored

By computing several performance indicators, a confusion matrix is used to gauge a classification algorithm's accuracy. It displays the classification model's correct and incorrect predictions with the dataset's actual values or intended results.

In this study, researchers took into account the predicted classes "CKD" and "not CKD." When predicting if a person has an illness, such as chronic kidney disease (CKD), "CKD" denotes that they have, but "not CKD" denotes that they do not.

TABLE I.    SHOWS THE CHARACTERISTICS OF CHRONIC KIDNEY DISEASE [11]

| Fields | Description |
|--------|-------------|
| age | Age |
| bp | Blood-pressure |
| sg | Specific-gravity |
| al | Albumin |
| su | Sugar |
| rbc | Red blood cells |
| pc | Pus-cell |
| pcc | Pus-cell clumps |
| ba | Bacteria |
| bgr | Blood-glucose random |
| bu | Blood-urea |
| sc | Serum-creatinine |
| sod | Sodium |
| pot | Potassium |
| home | Hemoglobin |
| pcv | Packed-cell volume |
| wc | White blood-cell count |
| rc | Red blood-cell count |
| htn | Hypertension |
| dm | Diabetes-mellitus |
| cad | Coronary artery-disease |
| appet | Appetite |
| pe | Pedal-edema |
| ane | Anemia |
| class | Class |

Also, investigators in this study employed the following indicators to assess how well our experiment performed using the confusion matrix in Table II.

True Positives (TP): These are cases that were accurately identified as positive, i.e., they had CKD when it was expected that they would.

- True Negative (TN): Instances that were appropriately identified as negative and were both predicted not to have CKD and really do not.

False Positive (FP) cases are those that were incorrectly identified as positive; they were expected to have CKD but didn't actually have it.

False Negatives (FN) are situations that were incorrectly categorized as negative; they were thought to be free of chronic renal disease but actually were.

- Accuracy: This pertains to the inherent ability of a classification algorithm to accurately anticipate and discern the underlying classes inherent within a given dataset. It is a metric that shows how accurately the classifiers assign the examples to the appropriate classes based on their projected class labels.

Accuracy is equal to (TP+TN)/(TP+TN+FP+FN).

TABLE II.    CONFUSION MATRIX TABLE

| Confusion Matrix | | | | |
|---|---|---|---|---|
| | Positive | Negative | Target Value | |
| Positive | TP | FN | Positive Predictive value | $\dfrac{TP}{TP+FP}$ |
| Negative | FP | TN | Negative Predictive value | $\dfrac{TN}{FN+TN}$ |
| | $\dfrac{TP}{TP+FP}$ Precision | $\dfrac{TP}{TP+FN}$ Recall | Accuracy= TP+TN/TP+FP+FN+TN | |

- Recall: It also goes by the name "sensitivity," and it gauges how well a classification algorithm can find pertinent examples.

Recall equals TP/ (TP+FN)

- Precision is a metric used by a classification system to evaluate how relevant the information that has been gathered is. It focuses on the percentage of retrieved instances that are relevant.

Precision is equal to TP / (TP+FP).

- F-Measure, sometimes referred to as the F-score, combines a test's recall and precision to determine how accurate it is. In order to assess the overall effectiveness of a classification system, it offers a balanced average of recall and precision.

F-Measure=2* (Recall + Precision) / (Recall*Precision)

- Receiver Operating Characteristics (ROC) Analysis: The Receiver Operating Characteristics (ROC) curve stands as a visual instrument of paramount significance for the appraisal of classification test efficacy. Presented graphically, it portrays the intricate interplay amidst the trade-offs between accurate identification and false positive occurrences across threshold variations. The ROC curve astutely encapsulates the nuanced balance between true positive and false positive outcomes, thereby facilitating a comprehensive comparison of distinct classification models. A pivotal gauge of model precision lies in the area under the ROC curve (AUC), a scalar metric ranging between 0 and 1. A value closer to 1 signifies a heightened model performance. Manifesting the capability to distinguish positive instances superiorly than negative instances, the AUC quantifies this discernment. On the ROC curve, the horizontal axis charts the false positive rate, while the vertical axis, often denoted as recall, delineates the true positive rate. A classification algorithm's performance and discriminatory ability are valuable revealed by the ROC curve.

TABLE III.    DISPLAYS THE RESULTS OF CLASSIFIERS BOTH WITH AND WITHOUT FEATURE SELECTION

| Categorization using feature selection techniques with and without | Precision | Recall | F-Measure | Accuracy |
|---|---|---|---|---|
| KNN absence of feature selection | 0.965 | 0.966 | 0.965 | 96.60 |
| KNN with JofeGainAttributeEval and ranker (chosen 20 Attributes) | 0.977 | 0.971 | 0.978 | 97.74 |
| KNN and Ranker with 15 Attributes) | 0.97 | 0.97 | 0.97 | 97 |
| Best first search engine with WrannerSubsetExal (Picked 8 attributes) | 0.98 | 0.98 | 0.98 | 98 |
| J48 absence of feature selection | 0.956 | 0.956 | 0.957 | 95.76 |
| JofeGainAttributeExal using a ranker (20 Attributes chosen) | 0.977 | 0.978 | 0.977 | 97.74 |
| J48 with JofeGajoAttributeEval and ranker (15 Attribute chosen) | 0.977 | 0.978 | 0.977 | 97.76 |
| Best first search engine 48 WrapperSubsetExal (7 attributes chosen) | 0.973 | 0.979 | 0.978 | 97.77 |
| ANN absence of feature selection | 0.968 | 0.968 | 0.968 | 96.65 |
| ANN and ranker with JofeGainAttributeEval (20 Attributes chosen) | 0.971 | 0.97 | 0.97 | 97 |
| ANN and ranker with JofeGainAttributeExal (15 Attribute chosen) | 0.976 | 0.965 | 0.975 | 97.55 |
| Best first search engine with WrannerSubsetExal and ANN (8 attributes chosen) | 0.975 | 0.979 | 0.976 | 97.78 |
| NB absence of feature selection | 0.941 | 0.935 | 0.936 | 93.25 |
| NB and ranker with Attributes chosen) | 0.942 | 0.938 | 0.938 | 93.45 |
| NB and ranker with JofeGainAstributeEval (15 Attributes chosen) | 0.956 | 0.953 | 0.952 | 95.12 |
| Best first search engine with WrannerSubsetEval and NB (9 attributes chosen) | 0.971 | 0.969 | 0.970 | 97 |
| SVM absence of feature selection | 0.968 | 0.969 | 0.968 | 96.76 |
| SVM and ranker with InfoGainAttributeEval 20 Attribute chosen) | 0.973 | 0.938 | 0.973 | 97.17 |
| SVM and ranker with InfoGainAttributeEval, 15 Attributes chosen) | 0.978 | 0.979 | 0.978 | 97.69 |
| Best first search engine SVM with WrapperSubsetEval and SVM (8 attributes chosen) | 0.971 | 0.972 | 0.973 | 97.12 |

In pursuit of enhanced precision in predicting Chronic Kidney Disease (CKD), a meticulous endeavor is made to curtail dataset dimensionality through strategic feature selection approaches. The Info Gain attribute evaluator synergistically combines forces with the ranker search engine, while the WrapperSubsetEval harnesses the prowess of the Best first search engine. By juxtaposing the outcomes against the original dataset, these methodologies ingeniously sculpt a novel dataset boasting reduced dimensions. The culmination of classifier results, with and without the application of feature selection techniques, finds concise summation in the depicted Table III above.

The dataset dimension for each classifier was 20 attributes as a result of the initial feature selection approach, which combined the infoGainAttributeEval evaluator with the ranker search engine. The infoGainAttributeEval evaluator and ranker search engine was then used in a second feature reduction procedure to further reduce the dimensionality, yielding a dataset characterized by 15 attributes per classifier, with the integration of the third feature selection strategy. The Best First search engine with the WrapperSubsetEval evaluator, resulting in a dataset dimension of eight attributes.

Without feature selection, all 25 characteristics were used in the K-nearest neighbour (KNN) classifier. The dataset dimensions for J48, ANN, Naive Bayes, and SVM classifiers were reduced to seven attributes for J48, ANN, and Naive Bayes, and eight attributes for SVM, using the WrapperSubsetEval evaluator with the Best First search engine.

Fig. 2 exhibits the empirical revelations pertaining to each classifier, juxtaposing their performance both in the presence and absence of the feature selection methodology. A comprehensive depiction of the classifiers' performance metrics, encompassing precision, recall, F-Measure, and accuracy, is meticulously presented within the same figure. In order to assess the CKD and non-CKD cohorts, discerning weighted averages were invoked as a robust analytical framework.

According to Fig. 2 findings, the ANN classifier's CKD prediction accuracy was highest when feature selection was combined with the WrapperSubsetEval and Best First search engines. The top-ranked average figures for precision, recall, F-Measure, and obtained using this method, which chose eight attributes from the original 25. The ANN classifier achieved a prediction accuracy of 97.78% for CKD without feature selection. The accuracy of the KNN classifier dropped to 97.55% when utilizing the InfoGainAttributeEval with ranker feature selection approach, demonstrating that the removal of some attributes had a detrimental effect on accuracy. As opposed to the accuracy of the normal dataset, which was 96.65%, the accuracy increased to 97% with the selection of 20 attributes.

When employing feature selection with InfoGainAttributeEval and ranker, the J48 classifier had the highest respectable accuracy in CKD prediction, as seen by the values in Fig. 3. The J48 classifier attained an accuracy of 97.75% approximately for both 15 and 20 specified attributes. The J48 classifier, on the other hand, showed a lower accuracy of 95.76% when predicting CKD without feature selection. The dataset was reduced to seven attributes using feature selection, WrapperSubsetEval, and the Best First search engine, and the J48 classifier showed a 97.77% accuracy rate compared to using the entire dataset with all 25 attributes; this accuracy rate was more significant.

The KNN classifier's accuracy rates for predicting CKD differed depending on the feature selection techniques used.

The KNN classifier acquired an accuracy rate of 96.60% in CKD prediction without requiring feature selection. The accuracy increased to 97.74% after implementing the InfoGainAttributeEval with a ranker feature selection approach and choosing 20 characteristics. However, when choosing 15 attributes utilizing the InfoGainAttributeEval with a ranker feature selection approach, the accuracy rate dropped to 97%. When dimensionality was reduced using the WrapperSubsetEval with the Best initial search engine feature selection method, the ANN classifier's accuracy rate on the CKD dataset increased. With eight qualities chosen, the accuracy rate was 98%.

The Naive Bayes classifier's accuracy rates for predicting CKD differed depending on the feature selection techniques used. The Nave Bayes classifier attained an accuracy rate of 93.25% in CKD prediction without requiring feature selection. The accuracy increased slightly to 93.45% after applying the InfoGainAttributeEval with a ranker feature selection approach and choosing 20 attributes. The accuracy rate increased to 95.12% while utilizing the InfoGainAttributeEval with a ranker feature selection approach and using 15 points. On the CKD dataset, dimensionality reduction utilizing the WrapperSubsetEval with the Best initial search engine feature

selection strategy led to the Naive Bayes classifier's most excellent accuracy rate, nine fields were chosen, and the accuracy rate was 98%.

Regarding predicting CKD, the SVM classifier's accuracy rates they differed according to the feature selection techniques used. Without feature selection, the SVM classifier only managed to predict CKD with an accuracy rate of 96.76%.

Graphical demonstration with and without feature selection, the precision, recall, and F-measures of chronic renal illness are compared in Fig. 2.

The accuracy increased to the highest rate of 97.17% after implementing the InfoGainAttributeEval with a ranker feature selection approach and choosing 20 characteristics. The accuracy rate amplified to 97.69% when 15 attributes were selected using the InfoGainAttributeEval with ranker feature selection approach. On the CKD dataset, dimensionality reduction utilizing the WrapperSubsetEval with the Best initial search engine feature selection strategy led to the SVM classifier's most excellent accuracy rate. 8 attributes were chosen, and the accuracy percentage was 97%. This rate, meanwhile, needed to be more accurate with the rate attained with the 20-dimensional dataset.
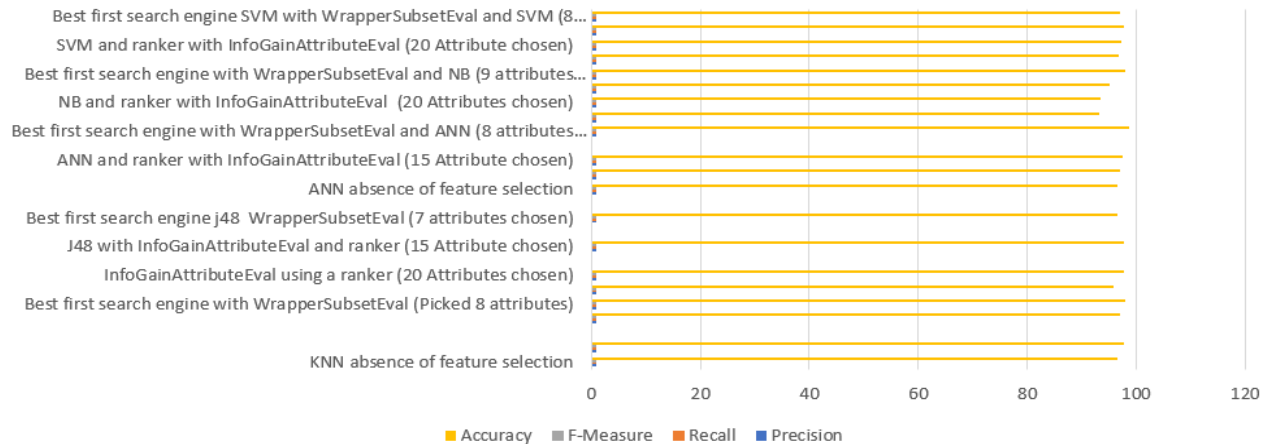


Fig. 2. Comparison of feature selection, precision, recall and F-measure of chronic renal illness.

TABLE IV.    EVALUATION OF CLASSIFIERS USING ENSEMBLE METHODS AND FEATURE SELECTION

| Classifier | Precision | Recall | F-Measure | Accuracy |
|---|---|---|---|---|
| KNN | 0.965 | 0.966 | 0.965 | 96.60 |
| KNN after FS | 0.98 | 0.98 | 0.980 | 98 |
| J48 | 0.956 | 0.956 | 0.957 | 95.76 |
| J4N after FS | 0.977 | 0.979 | 0.978 | 97.77 |
| ANN | 0.958 | 0.968 | 0.968 | 96.55 |
| ANN after FS | 0.977 | 0.979 | 0.976 | 97.78 |
| NR | 0.971 | 0.969 | 0.936 | 93.25 |
| NB after FS | 0.968 | 0.969 | 0.970 | 97 |
| SVM | 0.968 | 0.969 | 0.968 | 96.79 |
| SVM after FS | 0.971 | 0.972 | 0.973 | 97.12 |
| Essemble model | 0.985 | 0.986 | 0.985 | 98.85 |

While evaluating the ensemble classifier model on the CKD dataset, an exhaustive scrutiny of performance metrics was conducted, encompassing accuracy, precision, recall, F-Measure, actual positive rate, and ROC comparisons. These comprehensive assessments were meticulously juxtaposed with the individual classifiers' corresponding outcomes. Impressively, the ensemble model showed a high accuracy rate in CKD prediction.

Performances of classifiers with and without methods for feature selection and assembly are shown in Table IV.

The envisaged ensemble framework outclassed other standalone base classifiers and was combined with most of our suggested feature selection techniques. Various performance metrics were used to compare the ensemble model to heterogeneous base classifiers with and without feature selection. The ensemble model used lower dimensions acquired by feature selection techniques, which helped reduce training time and computing expenses. By cutting costs and execution time, feature selection increased accuracy. Fig. 3 shows that the ensemble model demonstrated the highest accuracy level for the CKD dataset compared to the individual base classifiers. It obtained 98.85% accuracy, 0.985% precision, 0.986% recall, and 0.985% F-Measure rates.
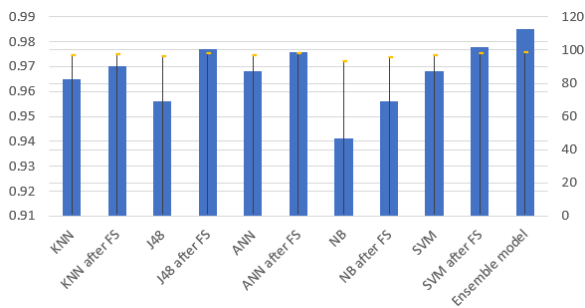


Fig. 3. Demonstrates the accuracy assessment of different classifiers.

Fig. 4 presents an insightful comparative analysis, meticulously evaluating the base classifier's level of correctness, exactness, and ability to retrieve relevant instances, both in the presence and absence of feature selection. Discernible in Fig. 4, the ensemble model decidedly outperformed the other classifiers. A comprehensive comparison of the ensemble's performance vis-à-vis that of the remaining classifiers for the dataset about chronic renal illness showcased the ensemble's profound superiority.
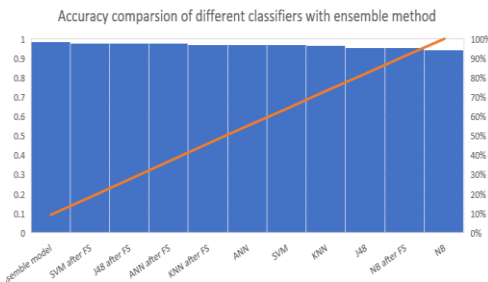


Fig. 4. Performance comparison of all the classifiers exploited in this study using a Pareto chart plot.

## V. CONCLUSION

In the pursuit of bolstering classifier precision, the present study diligently harnessed an arsenal of feature selection methodologies and strategically integrated ensemble models within the domain of the CKD dataset. Each classifier was guided by a distinct feature selection evaluator, encompassing the sophisticated InfoGainAttributeEval, the meticulous Ranker search platform, and the astute WrapperSubsetEval feature seamlessly integrated with the proficient Adept Best-First Search mechanism. The strategic application of these techniques was intricately woven into both the ensemble model and the proposed feature selection approach, amplifying the precision of the machine learning classifiers. The performance of K-Nearest Neighbors (KNN), J48, Artificial Neural Networks (ANN), Naïve Bayes (NB), and Support Vector Machine (SVM) classifiers was meticulously juxtaposed across the CKD dataset, and a refined subset crafted through WrapperSubsetEval, featuring the Best First Search Engine and InfoGainAttributeEval as feature selection evaluators. The experimental findings showed that increasing the dataset's dimension decreased the classifiers' accuracy. In particular, the accuracy of ANN classification using WrapperSubsetEval and the Best First search engine on the condensed dataset was 97.78%, exceeding the accuracy attained using the primary dataset and various approaches to feature selection. Contrasted against the unaltered dataset and alternative feature selection methodologies, the condensed dataset derived through the astute combination of InfoGainAttributeEval and the ranker search engine exhibits a remarkable accuracy pinnacle of 97.77% in the realm of J48 classification. With WrapperSubsetEval and the Best initial search engine, the KNN classification accuracy on the condensed dataset reached 98%, the most fantastic accuracy of any approach. With the help of WrapperSubsetEval and the Best first search engine, Naive Bayes classification was 97% accurate on the smaller dataset, outperforming the original dataset and other feature selection techniques. In parallel to the accuracy achieved using the initial dataset and various feature selection techniques, the SVM classifier achieved an impressive precision of 97.12% on the improved dataset generated by employing InfoGainAttributeEval in combination with the ranker search engine. These techniques engendered a discernible reduction in the false positive rate, concomitantly fostering an augmentation in the actual positive rate. Furthermore, an encompassing enhancement encompassed performance metrics alternatively, terms like accuracy, sensitivity, harmonic mean of precision and recall, and exact positive ratio. The ensemble techniques proposed demonstrated superior performance in classifying and predicting CKD on the provided dataset, as evidenced by the experimental results of these ensemble methods. On the condensed CKD dataset, the ensemble classification's accuracy exceeded that of the individual base classifiers by 98.85%. Looking to the future, the ensemble techniques we proposed showcased superior performance in classifying and predicting CKD on the provided dataset, as demonstrated by the impressive accuracy rate of 98.85%. In the upcoming research, further exploration of ensemble methods and feature selection techniques can be pursued to enhance CKD prediction models. Additionally, investigating the

generalizability of these techniques to other medical diagnoses and datasets would be a promising direction for future research in the domain of machine learning and healthcare.

REFERENCES

[1] Chandel, K.; Kunwar, V.; Sabitha, S.; Choudhury, T.; Mukherjee, S. A Comparative Study on Thyroid Disease Detection Using K-Nearest Neighbor and Naive Bayes Classification Techniques. CSI Transactions on ICT 2016, 4, 313–319, doi:10.1007/S40012-016-0100-5.

[2] Padmanaban, K.; Journal, G.P.-I.; 2016, undefined Applying Machine Learning Techniques for Predicting the Risk of Chronic Kidney Disease. sciresol.s3.us-east-2.amazonaws KRA Padmanaban, G ParthibanIndian Journal of Science and Technology, 2016•sciresol.s3.us-east-2.amazonaws … 9, doi:10.17485/ijst/2016/v9i29/93880.

[3] Majid, M.; Gulzar, Y.; Ayoub, S.; Khan, F.; Reegu, F.A.; Mir, M.S.; Jaziri, W.; Soomro, A.B. Enhanced Transfer Learning Strategies for Effective Kidney Tumor Classification with CT Imaging. International Journal of Advanced Computer Science and Applications 2023, 14, 2023, doi:10.14569/IJACSA.2023.0140847.

[4] Boukenze, B.; Haqiq, A.; Mousannif, H. Predicting Chronic Kidney Failure Disease Using Data Mining Techniques. Lecture Notes in Electrical Engineering 2017, 397, 701–712, doi:10.1007/978-981-10-1627-1_55.

[5] Dhiman, P.; Bonkra, A.; Kaur, A.; Gulzar, Y.; Hamid, Y.; Mir, M.S.; Soomro, A.B.; Elwasila, O. Healthcare Trust Evolution with Explainable Artificial Intelligence: Bibliometric Analysis. Information 2023, Vol. 14, Page 541 2023, 14, 541, doi:10.3390/INFO14100541.

[6] Polat, H.; Danaei Mehr, H.; Cetin, A. Diagnosis of Chronic Kidney Disease Based on Support Vector Machine by Feature Selection Methods. J Med Syst 2017, 41, doi:10.1007/S10916-017-0703-X.

[7] Dulhare, U.; Conference, M.A.-2016 I.I.; 2016, undefined Extraction of Action Rules for Chronic Kidney Disease Using Naïve Bayes Classifier. ieeexplore.ieee.orgUN Dulhare, M Ayesha2016 IEEE International Conference on Computational Intelligence, 2016•ieeexplore.ieee.org.

[8] Radhakrishnan, J.; Mohan, S. KI Reports and World Kidney Day. Kidney Int Rep 2017, 2.

[9] Sedighi, Z.; Ebrahimpour-Komleh, H.; Mousavirad, S.J. Feature Selection Effects on Kidney Desease Analysis. In Proceedings of the 2nd International Congress on Technology, Communication and Knowledge, ICTCK 2015; 2016.

[10] Khan, F.; Ayoub, S.; Gulzar, Y.; Majid, M.; Reegu, F.A.; Mir, M.S.; Soomro, A.B.; Elwasila, O. MRI-Based Effective Ensemble Frameworks for Predicting Human Brain Tumor. Journal of Imaging 2023, Vol. 9, Page 163 2023, 9, 163, doi:10.3390/JIMAGING9080163.

[11] National Kidney Foundation Global Facts: About Kidney Disease Available online: https://www.kidney.org/kidneydisease/global-facts-about-kidney-disease (accessed on 12 October 2023).

[12] Bashir, S.; Qamar, U.; Khan, F.H.; Javed, M.Y. MV5: A Clinical Decision Support Framework for Heart Disease Prediction Using Majority Vote Based Classifier Ensemble. Arab J Sci Eng 2014, 39, doi:10.1007/s13369-014-1315-0.

[13] Bashir, S.; Qamar, U.; Khan, F.H.; Naseem, L. HMV: A Medical Decision Support Framework Using Multi-Layer Classifiers for Disease Prediction. J Comput Sci 2016, 13, doi:10.1016/j.jocs.2016.01.001.

[14] Khajehali, N.; Alizadeh, S. Extract Critical Factors Affecting the Length of Hospital Stay of Pneumonia Patient by Data Mining (Case Study: An Iranian Hospital). Artif Intell Med 2017, 83, doi:10.1016/j.artmed.2017.06.010.

[15] Pritom, A.I.; Munshi, M.A.R.; Sabab, S.A.; Shihab, S. Predicting Breast Cancer Recurrence Using Effective Classification and Feature Selection Technique. In Proceedings of the 19th International Conference on Computer and Information Technology, ICCIT 2016; 2017.

[16] Gulzar, Y. Fruit Image Classification Model Based on MobileNetV2 with Deep Transfer Learning Technique. Sustainability 2023, 15, 1906.

[17] Dhiman, P.; Kaur, A.; Balasaraswathi, V.R.; Gulzar, Y.; Alwan, A.A.; Hamid, Y. Image Acquisition, Preprocessing and Classification of Citrus Fruit Diseases: A Systematic Literature Review. Sustainability 2023, Vol. 15, Page 9643 2023, 15, 9643, doi:10.3390/SU15129643.

[18] Mamat, N.; Othman, M.F.; Abdulghafor, R.; Alwan, A.A.; Gulzar, Y. Enhancing Image Annotation Technique of Fruit Classification Using a Deep Learning Approach. Sustainability 2023, 15, 901.

[19] Gulzar, Y.; Ünal, Z.; Akta¸s, H.A.; Mir, M.S. Harnessing the Power of Transfer Learning in Sunflower Disease Detection: A Comparative Study. Agriculture 2023, Vol. 13, Page 1479 2023, 13, 1479, doi:10.3390/AGRICULTURE13081479.

[20] Aggarwal, S.; Gupta, S.; Gupta, D.; Gulzar, Y.; Juneja, S.; Alwan, A.A.; Nauman, A. An Artificial Intelligence-Based Stacked Ensemble Approach for Prediction of Protein Subcellular Localization in Confocal Microscopy Images. Sustainability 2023, Vol. 15, Page 1695 2023, 15, 1695, doi:10.3390/SU15021695.

[21] Gulzar, Y.; Hamid, Y.; Soomro, A.B.; Alwan, A.A.; Journaux, L. A Convolution Neural Network-Based Seed Classification System. Symmetry (Basel) 2020, 12, 2018.

[22] Malik, I.; Ahmed, M.; Gulzar, Y.; Baba, S.H.; Mir, M.S.; Soomro, A.B.; Sultan, A.; Elwasila, O. Estimation of the Extent of the Vulnerability of Agriculture to Climate Change Using Analytical and Deep-Learning Methods: A Case Study in Jammu, Kashmir, and Ladakh. Sustainability 2023, Vol. 15, Page 11465 2023, 15, 11465, doi:10.3390/SU151411465.

[23] Albarrak, K.; Gulzar, Y.; Hamid, Y.; Mehmood, A.; Soomro, A.B. A Deep Learning-Based Model for Date Fruit Classification. Sustainability 2022, 14.

[24] Sahlan, F.; Hamidi, F.; Misrat, M.Z.; Adli, M.H.; Wani, S.; Gulzar, Y. Prediction of Mental Health Among University Students. International Journal on Perceptive and Cognitive Computing 2021, 7, 85–91.

[25] Hamid, Y.; Elyassami, S.; Gulzar, Y.; Balasaraswathi, V.R.; Habuza, T.; Wani, S. An Improvised CNN Model for Fake Image Detection. International Journal of Information Technology 2022 2022, 1–11, doi:10.1007/S41870-022-01130-5.

[26] Gulzar, Y.; Alwan, A.A.; Abdullah, R.M.; Abualkishik, A.Z.; Oumrani, M. OCA: Ordered Clustering-Based Algorithm for E-Commerce Recommendation System. Sustainability 2023, Vol. 15, Page 2947 2023, 15, 2947, doi:10.3390/SU15042947.

[27] Gulzar, Y.; Khan, S.A. Skin Lesion Segmentation Based on Vision Transformers and Convolutional Neural Networks&mdash;A Comparative Study. Applied Sciences 2022, Vol. 12, Page 5990 2022, 12, 5990, doi:10.3390/APP12125990.

[28] Khan, S.A.; Gulzar, Y.; Turaev, S.; Peng, Y.S. A Modified HSIFT Descriptor for Medical Image Classification of Anatomy Objects. Symmetry (Basel) 2021, 13, 1987.

[29] Alam, S.; Raja, P.; Gulzar, Y. Investigation of Machine Learning Methods for Early Prediction of Neurodevelopmental Disorders in Children. Wirel Commun Mob Comput 2022, 2022.

[30] Ayoub, S.; Gulzar, Y.; Reegu, F.A.; Turaev, S. Generating Image Captions Using Bahdanau Attention Mechanism and Transfer Learning. Symmetry (Basel) 2022, 14, 2681.

[31] Hanafi, M.F.F.M.; Nasir, M.S.F.M.; Wani, S.; Abdulghafor, R.A.A.; Gulzar, Y.; Hamid, Y. A Real Time Deep Learning Based Driver Monitoring System. International Journal on Perceptive and Cognitive Computing 2021, 7, 79–84.

[32] Hamid, Y.; Wani, S.; Soomro, A.B.; Alwan, A.A.; Gulzar, Y. Smart Seed Classification System Based on MobileNetV2 Architecture. In Proceedings of the 2022 2nd International Conference on Computing and Information Technology (ICCIT); IEEE, 2022; pp. 217–222.

[33] Mehmood, A.; Gulzar, Y.; Ilyas, Q.M.; Jabbari, A.; Ahmad, M.; Iqbal, S. SBXception: A Shallower and Broader Xception Architecture for Efficient Classification of Skin Lesions. Cancers 2023, Vol. 15, Page 3604 2023, 15, 3604, doi:10.3390/CANCERS15143604.

[34] Gulzar, Y.; Alkinani, A.; Alwan, A.A.; Mehmood, A. Abdomen Fat and Liver Segmentation of CT Scan Images for Determining Obesity and Fatty Liver Correlation. Applied Sciences 2022, Vol. 12, Page 10334 2022, 12, 10334, doi:10.3390/APP122010334.

[35] Anand, V.; Gupta, S.; Gupta, D.; Gulzar, Y.; Xin, Q.; Juneja, S.; Shah, A.; Shaikh, A. Weighted Average Ensemble Deep Learning Model for Stratification of Brain Tumor in MRI Images. Diagnostics 2023, Vol. 13, Page 1320 2023, 13, 1320, doi:10.3390/DIAGNOSTICS13071320.

[36] Ayoub, S.; Gulzar, Y.; Rustamov, J.; Jabbari, A.; Reegu, F.A.; Turaev, S. Adversarial Approaches to Tackle Imbalanced Data in Machine Learning. Sustainability 2023, Vol. 15, Page 7097 2023, 15, 7097, doi:10.3390/SU15097097.

# AHP-based Design of a Finger Training Device for Stroke

Hua Wei[1]*, Ding-Bang Luh[2], Xin Li[3], Hai-Xia Yan[4]

School of Art and Design, Guangdong University of Technology, Guangzhou, China[1, 2, 3]

School of Arts, Shaanxi University of Technology, Hanzhong, China[4]

*Abstract*—This study aims to develop a stroke finger training device specifically for office hand scenes which exercises the small muscles of the fingertips and improves the hand strength of stroke patients. The device has a real-time recording function for muscle strength changes during finger muscle training and enhances interaction through the feedback of training device data, thereby improving training effectiveness. This research involves analyzing hand postures and muscle movements in computer office scenes, designing questionnaires to obtain user requirements, and using the Delphi analysis method to screen key indicators and form standards and program layers. The Analytic Hierarchy Process (AHP) evaluates and ranks the core design elements. According to the design elements, the structure and training system design are guided, and a prototype is built for experimental testing. The results show that the training device effectively improves participants' hand strength, stability, and coordination and helps restore hand function. The AHP method allows for evaluating and ranking the device's design elements, making the device design more reasonable and comprehensive. Overall, the training device significantly improves the finger muscle strength of participants.

*Keywords—Stroke; rehabilitation training equipment; finger muscle strength; AHP; specific finger actions*

## I. INTRODUCTION

The incidence of stroke in China has been increasing yearly, and the number of young stroke patients has also increased in recent years [1-3]. Studies have shown that approximately 80% of stroke survivors experience finger dysfunction, especially abnormal finger muscle strength, which seriously affects their daily life and work ability [4,5]. Therefore, finger training has become a crucial part of rehabilitation treatment. Rehabilitation training usually requires rehabilitation equipment, as it can help patients restore joint mobility, increase muscle strength, improve finger coordination, relieve pain, prevent finger stiffness, and improve the quality of life [6].

However, research on existing patents, products, and literature shows that finger rehabilitation training equipment has the following characteristics.

From the perspective of device types, the significant classifications of hand rehabilitation training devices include exoskeletons and end-effectors, which include devices that encourage repetitive hand movements [7], peripheral sensory stimulation devices that promote sensory-motor control [8], and neuromuscular stimulation devices [9]. Based on the principle of neural reshaping [10], exoskeleton devices for finger rehabilitation simulate joint movements of the fingers or optimize materials to fit the hand joints better to promote movement of the affected limb and achieve neural reshaping for rehabilitation purposes.

For example, Luo Guangda et al. [11] designed a hand rehabilitation robot that optimizes its movement mechanism to simulate the movements of the distal interphalangeal joint, proximal interphalangeal joint and metacarpophalangeal joint, achieving finger flexion, extension and abduction. Wang Yangwei et al. [12] used shape memory alloy (SMA) filaments as actuators and adopted a soft glove structure for the hand exoskeleton, which has the advantages of good movement flexibility and high finger fit. End-effectors mainly focus on local hand movements to improve hand movement abilities. For instance, Fang Yufei et al. [13] proposed a hand finger rehabilitation device consisting of a base and a finger ring, which achieves finger flexion and extension through a long-pitched screw rotating inward, with a simple and compact structure, but limited in the direction of force, primarily simulating the force generation at the fingertips or distal phalanges towards the palms, which is seen in grasping actions, but not in other daily activities like picking, pinching, or tapping movements.

Regarding rehabilitation training objectives, the available devices can be divided into two categories: devices for strengthening the hands (using springs and other resistance equipment) and devices for training the range of motion of the fingers (using elastic rods and other devices). From the perspective of technological implementation, they can be further divided into virtual reality finger training devices (to enhance the training experience) and electric finger training devices (using sensing technology [14] and feedback [15] systems to help patients master movement techniques). From the perspective of design pathways, current rehabilitation training devices focus on optimizing drivers, controls [16], structures and trajectory lines [17-20].

While existing devices have played an essential role in the finger rehabilitation process, they lack specific muscle training for finger joint-specific movement positions (such as the particular movement involved in exerting force in a fixed direction at the fingertips in a working environment) and have limited ability to train the small muscles of each finger joint. For example, they mainly focus on overall finger extension and flexion [21], lacking individual finger and finger coordination training. Additionally, existing rehabilitation devices lack real-time feedback capabilities. Furthermore, young stroke patients who need to return to work require specific finger movements,

which existing rehabilitation training devices lack. They cannot help patients transfer their practice skills to actual work, thus compromising the effectiveness of rehabilitation practice. Therefore, developing an effective finger training device is significant for stroke rehabilitation and can improve the patient's quality of life and rehabilitation effects.

This paper proposes the design of a stroke finger training device using the AHP method, which provides personalized movement training for specific hand movements and prepares young and middle-aged stroke patients to return to work. Firstly, we introduce the basic principles and steps of the AHP method. Then, based on scenario analysis and finger posture analysis, we obtain the finger training needs of stroke patients, determine the device's design requirements and functional modules, and evaluate and rank the importance of each functional module according to the AHP method, thereby determining the final design scheme.

To verify the feasibility of the design scheme, we built a testing prototype and developed testing software. In terms of hardware, we adopted a button training structure and used sensors and self-generated force to achieve finger strength, and coordination training. In terms of software, we developed a simple interactive application program that can adjust training difficulty, record and analyze data, and perform other functions.

Finally, we analyzed the test results, which showed that the device could effectively improve the people's finger muscle strength. At the same time, the device has good adjustability and personalized features, which can be adjusted and optimized according to the needs of different patients, providing new ideas and methods for stroke finger rehabilitation training.

The main contributions of this paper are as follows:

*1)* From the perspective of industrial design, a rehabilitation training device that can record real-time finger force data is designed using the AHP method.

*2)* The paper proposes finger strength training for the distal finger joints of patients and emphasizes the importance of finger force exertion in work scenarios. The changes in muscle strength are used as parameters to evaluate the training progress.

## II. RELATED WORK

### A. Mechanisms of Hand Movement Training in Stroke Patients

Stroke can cause ischemia or bleeding in some brain regions, damaging motor pathways such as the corticospinal and pyramidal tract [22]. This damage can result in motor limitations and hand dysfunction [23]. Hand movement therapy primarily targets the damage caused by stroke to the motor pathways by promoting regeneration and reconstruction of these pathways and improving the patient's hand muscle strength, coordination, and fine motor skills [24].

Hand movement therapy includes active and passive movement training, such as hand stretching, grip exercises, and finger range of motion training. These exercises can be selected and combined based on the patient's specific needs to achieve

the best rehabilitation results [25]. It is important to note that hand movement therapy is not suitable for all stroke patients, as different types and degrees of stroke can lead to various neurological damage and rehabilitation requirements [26]. Therefore, professional assessment and individualized rehabilitation plans need to be developed before conducting hand movement therapy, and the training process and intensity need to be quantified during the rehabilitation process.

### B. The basic Principles and Steps of AHP

Analytic Hierarchy Process (AHP) was first proposed by American mathematician and decision scientist Thomas L. Saaty [27]. It is a multi-criteria decision-making method used to determine the relative importance of various factors in complex problems [28]. Its basic principle is to decompose the decision-making problem into multiple levels, from overall to detail, to determine the weight relationships between factors at each level and obtain the decision-making result. The specific steps are as follows:

Step 1: Determine the decision-making objectives and criteria. The various indicators at each level are obtained through questionnaires and the Delphi method.

The initial design elements were obtained by collecting 89 valid questionnaires. Five experienced rehabilitation physicians were invited as experts to determine the criteria and program design elements at the guideline and program layers. The Delphi method used in this study followed the rule of majority decision, with the consensus reached by the experts as the screening result for each round. The objective is denoted as O, the guideline layer as G, and the program layer as P.

Step 2: Construct the judgment matrix A_X. The scale type is 1-9[29, 30]. Experts are invited to construct the judgment matrix for each level element based on the scale type to evaluate the relative importance of each criterion. X refers to the judgment objects for constructing the judgment matrix A, such as the criteria-level G judgment matrix A_G for this research case, which can be represented as follows in the paper translation.

$$A_G = \begin{bmatrix} a_{11}(G1/G1) & \cdots & a_{11}(G1/G5) \\ \vdots & \ddots & \vdots \\ a_{11}(G5/G1) & \cdots & a_{ij}(G5/G5) \end{bmatrix} \tag{1}$$

*i* represents the row number of the matrix, and *j* represents the column number of the matrix.

Step 3: Calculate the weight vector $W_i$.

$$W_i = \sum_{i=1}^{n}\left(\frac{a_{ij}}{\sum_{j=1}^{n} a_{ij}}\right) \tag{2}$$

*n* represents the order of the matrix.

Step 4: Consistency check.

$$CR = \frac{\lambda_{max}-n}{(n-1)RI} < 0.1 \tag{3}$$

Calculate the maximum eigenvalue for each matrix

$$\lambda_{max} = \sum_{i=1}^{n} \frac{A_X * Wi}{nWi} \tag{4}$$

The matrix is considered acceptable when the consistency ratio $CR$ is less than 0.1.

Step 5: Synthesize the total weight. The calculation method is the same as Formula (2).

In practical operations, the software can carry out the above calculation process. This study used a Matlab program for calculation.

### C. Application of AHP to Product Design

AHP is a commonly used multi-criteria decision-making analysis method widely applied in many fields. In product design, Yang et al. [31] used AHP to analyze various aspects of design proposals for bathroom products. By analyzing different demand factors and determining their weights, the best solution can be obtained, and a bathroom product that meets user needs and balances various requirements such as aesthetics, economy, and environmental protection can be designed. Liu et al. [32] studied user behaviour workflows using the Symbolic Analysis Pathway Allotment Diagram (SAPAD), analyzed weights using AHP, and finally proposed a modified design plan for an intelligent charging station that meets users' needs. Wang et al. [33] used AHP to rank the design elements by weight and importance. They combined them with a fuzzy model to complete the packaging design of Baihua Honey agricultural products in Weixi County, Lijiang.

Therefore, AHP is a fundamental decision-making method that can be used independently or in combination with other methods to play a role in product design. In product design, AHP helps designers determine the optimal design solution and the weight of design elements, providing strong support for the design process.

### III. MATH-HIERARCHICAL MODEL OF FINGER TRAINING NEEDS FOR YOUNG PEOPLE WITH STROKE

### A. Situational Analysis

Computers are standard office equipment, and when patients manipulate the keyboard, their fingers need to perform combined movements of extension and flexion and exert force to hit the keys. Patients with high muscle tension may have difficulty extending their fingers, while those with muscle weakness may have difficulty exerting force, resulting in difficulty pressing the keys. Inflexible fingers can also reduce critical efficiency and cause mistakes, ultimately affecting work quality. Therefore, this study proposes the analysis of design requirements for training devices targeting the scenario of pressing the keyboard, as shown in Fig. 1.

### B. Finger Posture and Muscle Analysis

According to the regularity of finger tapping on the keyboard, ignoring critical shortcut operations, only one finger taps the keyboard at a time. The fingers maintain a natural flexed state, with the tapping finger pressing down and the other fingers exerting an upward force to prevent mistakes. As shown in Fig. 2, two postures are maintained when tapping the keyboard, achieved through the cooperation of the finger extensor and flexor muscles. According to the anatomy of the fingers, the finger extensor muscles are located on the back of the fingers and mainly exert their effects through the extensor

tendon cap, which is composed of the central tendon bundle and the lateral bundle, acting on the finger bones and exerting an extension effect. The finger flexor muscles inside the fingers achieve finger flexion. The four fingers are usually powered by the palm-to-finger joints, except for the thumb, passing through the proximal phalanx, middle phalanx, and ending at the distal phalanx tubercle. The thumb taps the keyboard less frequently and relies on the wrist and palm bones to reach the thumb tubercle. The force direction of the fingertips is perpendicular to the operating plane and downwards.
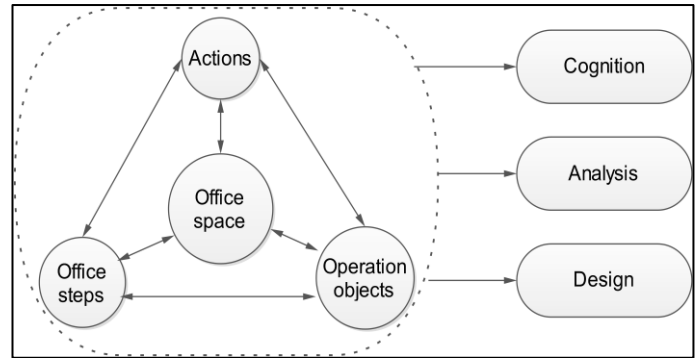


Fig. 1.  Situation analysis chart.

### C. AHP Hierarchical Model Construction

Based on the analysis of scenarios, finger posture, and muscle analysis, a questionnaire was designed for research, and primary indicators were obtained through cluster analysis. Rehabilitation therapists, equipment designers, and patients were invited to conduct indicator screening through the Delphi method. The indicator hierarchy was determined, and the final weights were calculated in Matlab according to the calculation principle of AHP in section 3.1, as shown in Fig. 3.
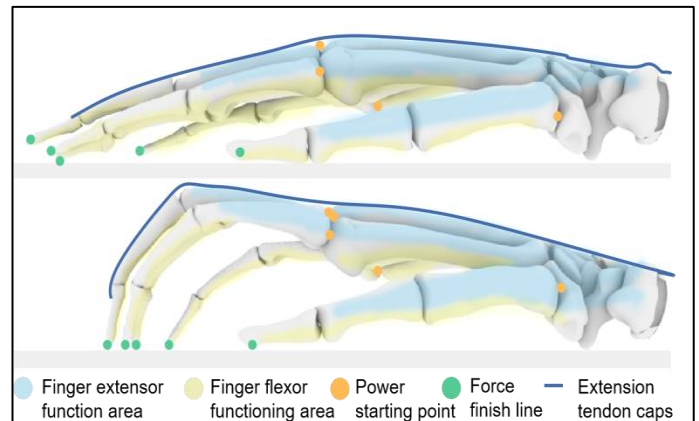


Fig. 2.  Finger posture and muscle action areas.

### IV. STROKE FINGER-TRAINING DEVICE DESIGN

According to the current overall ranking of the hierarchy, the main design elements need to be considered comprehensively in the quasi-side layer's corresponding elements and scheme layers. Based on this weight, the scheme's design can be carried out.
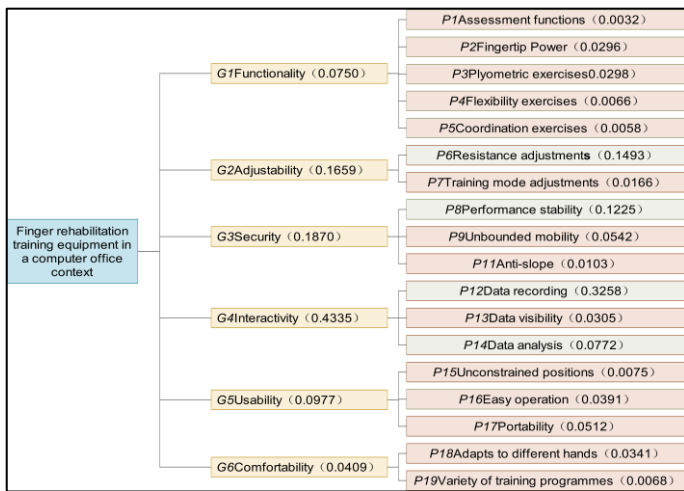
Fig. 3.    Finger-training equipment design guidelines levels and weights.

## A.  Structural Design

Considering that finger force training requires a certain amount of resistance, and the force data and effective force frequency will serve as guiding parameters for finger muscle strength training, this study adopts PROE for modular design. The elements that make up the design of (a) keyboard structure is a pressing column, (b) spring limiting grooves, (c) enclosure, (d) spring, (e) retaining ring for the spring, (f) winding head, (g) coil, (h) force transducer, and (i) soldering point for the coil (see Fig. 4). The principle is to provide resistance to the small muscles of the hand through the compression of the spring by pressing the pressing column and to obtain finger force data through the force sensor. The electromagnetic induction principle of the current change produces the compelling force frequency.
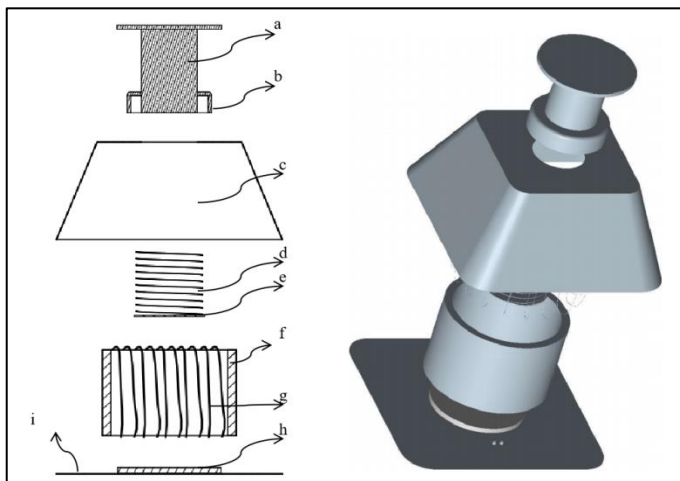


Fig. 4.    Keypad construction parts, (a) pressing post, (b) spring limit slot, (c) housing, (d) spring, (e) spring retaining spacer, (f) winding post, (g) coil, (h) force sensor, (i) coil terminal.

Different springs can be replaced individually according to the muscle strength ability of different patients, gradually increasing or decreasing the spring elasticity to adapt to the needs of patients. The pressing column (a) and the spring limit threads connect the column slot. The bottom of the pressing

column has magnetism. When the pressing column is pressed down, the spring contracts and the magnetic field lines of the magnet below the pressing column cut the coil, thereby affecting the direction of the coil current. The frequency of force is obtained by measuring the current's direction and number of changes. The spring and spring fixing gasket are fixedly connected to limit the spring from running and to facilitate the upper surface of the force sensor to contact fully, obtaining more accurate force measurement. Each keyboard structural component is connected to the controller and power supply through the wiring terminal, and the training results are displayed on the display screen through the data processor. The housing of the keyboard structural component allows the pressing column to pass through first and then fixes the spring limit slot with the pressing column bolt. It is fixed to the bottom surface of the keyboard by a buckle or adhesive, playing a role in dust-proofing and protection of the internal structure.

## B.  Training System Design

The training system consists of two parts: training programs and training operations. The relevant modules and logical relationships are shown in Fig. 5. Patients must first complete an assessment to determine whether they can actively move. According to the muscle strength grading standards established by the American Society of Rehabilitation Medicine (ASRM), the difference between grade 0 (no muscle activity) and grade 1 (slight muscle contraction but unable to move the joint) is muscle contraction. Therefore, a grade of 1 or higher indicates active movement.

During the test to determine whether the patient can actively move, data is collected when the patient presses the keyboard. The intelligent algorithm calculates the corresponding training program output and evaluation result based on the collected data. The initial data is used to assess whether the patient has muscle strength. Data analysis displays instructions and evaluation results on the screen to guide the patient in operating the keyboard. The intelligent algorithm is further optimized through repeated training and data accumulation iterations.
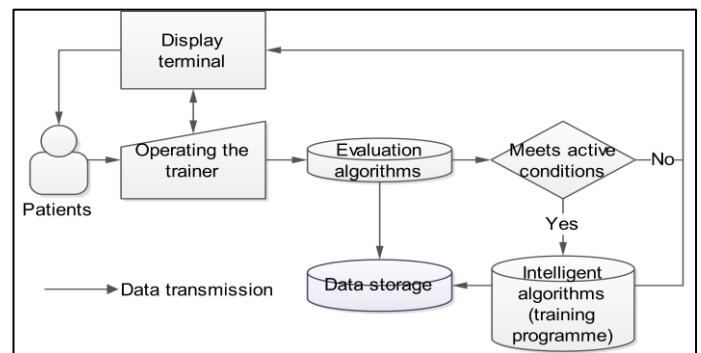


Fig. 5.    Finger training system.

## C.  Training Methods

This training device is designed for finger strength and fingertip coordination training in a computer office setting. Compared to existing finger strength training devices, the training method in this study explicitly targets the finger force

direction and coordination required in office scenarios. Previous research has shown evidence that standard keyboards can improve the fine motor skills of the fingers when typing [34, 35] and their coordination [36]. This training device adjusts the critical resistance and provides interactive feedback to facilitate finger movements. It allows patients to control their finger force, including the appropriate force activation of the keys, control of force direction, force magnitude, and speed. During the training process, patients are expected to exert force vertically on the keyboard surface to activate the muscles in their fingertips, thus achieving better rehabilitation outcomes.

The overall solution consists of a keyboard structure and display screen. The keyboard structure simulates the layout of a keyboard and can be configured for single or double-handed operation, allowing for single and double-handed training. Depending on the patient's level of disability, either a single or double keyboard may be used. The single keyboard primarily focuses on training individual letters, emphasizing muscle strength training. In contrast, the double keyboard focuses on meaningful word or sentence combinations, emphasizing finger coordination training. Since both keyboards are interchangeable, the program must be configured to recognize which hand, left or right, is associated with the selected keyboard. The keyboard and screen interface uses a standard USB interface. The display screen can be a regular monitor or touchscreen, as shown in Fig. 6.
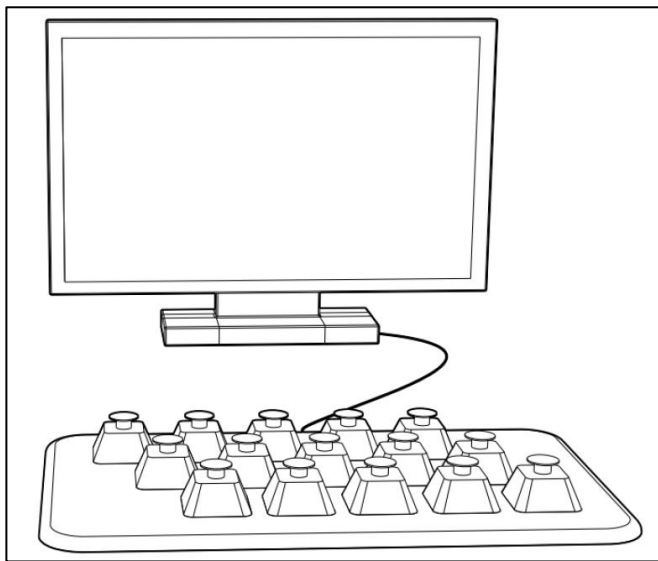


Fig. 6. One-handed training configuration illustration.

During training, posture is essential. Patients are instructed to adjust to a comfortable sitting position and relax their hand posture. Fingers should be placed on the training keyboard, and precise finger movement is achieved by tapping the keyboard with fingertips or finger pads. During single-handed training, the system configures the corresponding keyboard letters for the affected hand based on on-screen prompts. The typical keyboard letters and positions are displayed on the screen, and the patient operates the keyboard after observing the prompts.

Data is recorded on the finger force and the frequency of force variation on a single key (quantified by the number of electrical current changes during crucial press). During double-handed training, the double keyboard is selected, and the screen interface is chosen for the corresponding hand's keyboard to avoid incorrect keyboard settings. The pre-set words, phrases, or sentences are then used for keyboard operation, with the completion time recorded as a basis for later evaluation.

## V. TESTS AND RESULTS

A prototype device and system have been developed, as shown in Fig. 7, to validate finger muscle strength and coordination. In addition to the designed structure of this research project, the hardware includes the FSR402 thin film pressure sensor and pressure sensing module. The upper computer is compiled using VC++ 6.0.

A total of 30 participants were recruited for this study, with ages ranging from 22 to 40 years old. All other participants were in good physical health except for one stroke patient. Due to the difficulty in finding stroke patients as participants, this study did not compare stroke patients with healthy participants. Instead, the study assumed that the device would have training effects on healthy individuals and be effective for stroke patients.

The participants were divided into two groups: Group 1 consisted of 15 participants who underwent single-handed training and testing (using their non-dominant hand). In contrast, Group 2 consisted of 15 participants who underwent dual-handed training and testing.

There was no separate control group in this study. The initial test values for each group were used as the control, and the program's feasibility was analyzed by comparing the data before and after training. For single-handed training, the letters "A, S, D, F" were pressed 20 times; for double-handed training, the phrase "WOAIWODEZUGUOZ" was pressed 20 times. Muscle strength increase was measured for the single-handed training, and hand coordination was measured for the double-handed training. Since data was collected in real-time, the final data was determined based on the last test results obtained for each finger after training completion. The test results are presented in Table I, Fig. 8, and Fig. 9.
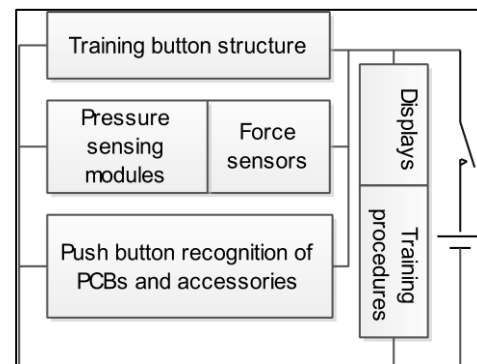


Fig. 7. Prototype schematic diagram.
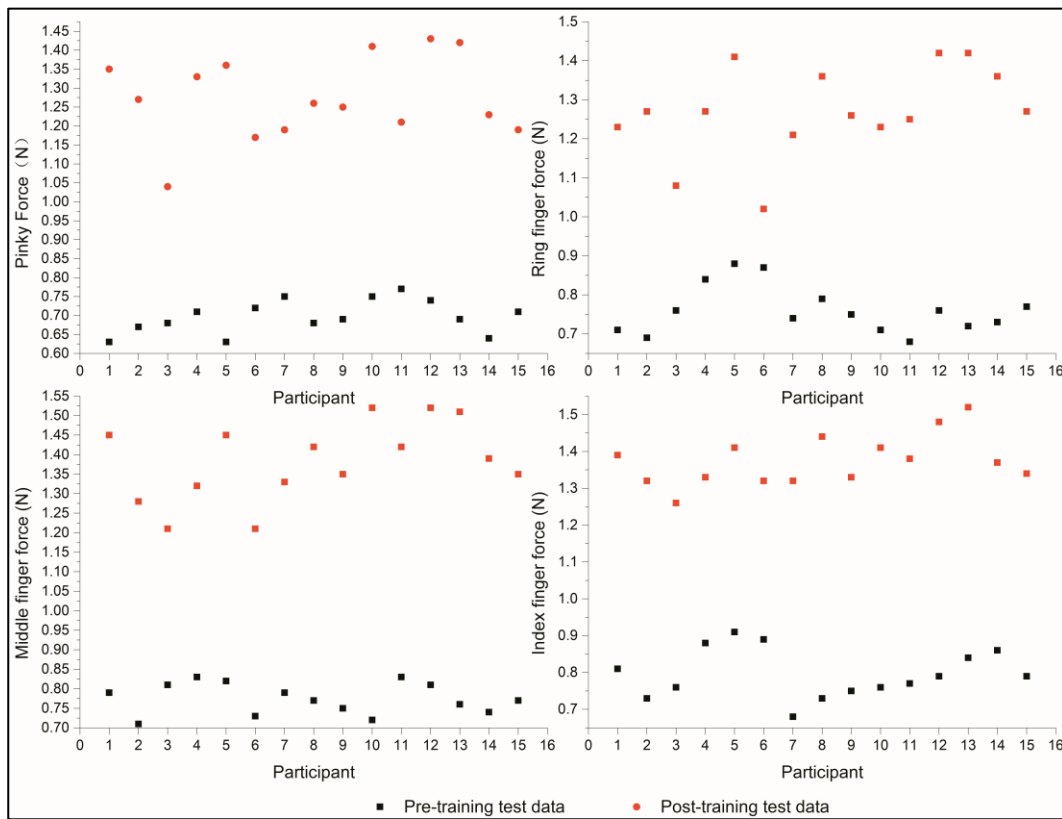
Fig. 8. Comparison of fingertip strength before and after one hand training.

TABLE I. ONE-HANDED TRAINING OF MUSCLE STRENGTH CHANGES AND FREQUENCY OF FORCE CHANGES

| CATEGORIES | | MUSCLE POWER (N) | | | | FREQUENCIES |
|---|---|---|---|---|---|---|
| | | Min | Max | Mean | SD | Mean |
| PRE-TRAINING | Pinky Finger | 0.63 | 0.77 | 0.70 | 0.04 | 4.33 |
| | Ring Finger | 0.68 | 0.88 | 0.76 | 0.06 | 3.87 |
| | Middle finger | 0.71 | 0.83 | 0.78 | 0.04 | 2.73 |
| | Index finger | 0.68 | 0.91 | 0.80 | 0.07 | 2.60 |
| POST-TRAINING | Pinky Finger | 1.04 | 1.43 | 1.27 | 0.11 | 1.67 |
| | Ring Finger | 1.02 | 1.42 | 1.27 | 0.12 | 1.07 |
| | Middle finger | 1.21 | 1.52 | 1.38 | 0.10 | 1.07 |
| | Index finger | 1.26 | 1.52 | 1.37 | 0.07 | 1.00 |

## VI. DISCUSSION

Based on the test data, Group 1 subjects showed varying degrees of increases in finger muscle strength after training, as shown in Fig. 8 and Table I: the force of the little finger increased from 0.70±0.04 (N) to 1.27±0.01 (N), the force of the ring finger increased from 0.76±0.06 (N) to 1.27±0.12 (N), the force of the middle finger increased from 0.78±0.04 (N) to 1.38±0.10 (N), and the force of the index finger increased from 0.80±0.07 (N) to 1.37±0.07 (N); the frequency of force change

decreased, and the mean range of changes before training of [2.6, 4.33] changed to [1, 1.67], indicating more stable force production. In Group 2, the training completion time decreased from 35.3±4.25 (S) before to 23.7±5.32 (S) after training, indicating improved finger coordination. The experimental results indicate that the stroke finger training device based on AHP can effectively improve stroke patients' recovery of finger function and coordination ability. During the training process, the finger muscle strength of the subjects was significantly improved, and the stability of force production and coordination ability was significantly improved.

The objective of this study is to increase finger muscle strength and control in stroke patients through the use of an active training device. However, there are certain limitations for patients using this device. Firstly, patients need to be able to extend their fingers and push individual fingers downward. Secondly, they need to increase the strength of their finger flexor muscles.

In this experiment, muscle strength testing is measured by the force exerted when pressing keyboard keys with the fingers. Based on general knowledge, humans tend to exert the minimum or moderate force necessary to achieve the desired movement. However, stroke patients with weaker finger muscles need to increase their finger muscle strength and improve their control over movements. Compared to the average peak force of 0.86N generated by healthy individuals pressing standard spring-column keyboards [37], this training device can generate a range of crucial contact forces, including 0.86N. Through training, patients' finger muscle strength

gradually increases. Healthy individuals typically exert the minimum force necessary to control their movements while pressing keys. However, to exercise the finger muscles of stroke patients, the spring resistance of the training device needs to be adjusted to accommodate the requirements of finger muscle training and enhance muscle strength.

However, increasing finger muscle strength training does not mean continuously increasing muscle strength. The goal is to exercise finger control so patients can perform finger-pressing operations required in office tasks. Therefore, this device adjusts the spring resistance for muscle strength training and protection. Whether further muscle strength training is needed depends on the muscle strength assessment conducted by the rehabilitation therapist.

This approach uses changes in muscle strength as an indicator, as individual muscle strength values do not fully represent the practical significance of rehabilitation muscle strength. The change in muscle strength value serves only as a reference for whether muscle strength gradually increases, combined with a reduction in task completion time to demonstrate the improvement in finger control ability after muscle strength training. The change in muscle strength value is not optimal for rehabilitation indicators, so this study did not consider the resolution of force change sensitivity. Choosing 20 training and testing key presses is not a standard for rehabilitation training frequency. This number is set to allow participants to become accustomed to the operation and reduce possible testing errors. The frequency should be set in actual training based on the patient's willingness and finger muscle condition.

In summary, this study aims to increase finger muscle strength and control in stroke patients through an active training device and to evaluate the training effects through changes in muscle strength and task completion time.

Compared with traditional devices [11-13], the main advantage of this rehabilitation training device is that it meets the exercise needs of finger operation on a computer through the keyboard structure in combination with a display screen and corresponding program settings, with active training being the focus. The device has several features: (1) it allows for free selection of single or double-handed training, and difficulty can be gradually increased based on the patient's finger movement deficiencies to improve both muscle strength and flexibility; (2) it can collect data in real-time, facilitating adjustments to the training program and evaluation of rehabilitation progress; (3) it has wide adaptability and can accommodate different finger sizes, without restrictions on the middle or distal finger joints, allowing patients more freedom to adjust their own posture; (4) costs are reduced, as the device can be modified based on existing keyboards, being highly feasible, and the keyboard operation is a familiar operation, which is easy for the patient to understand and learn, making it easy to promote; (5) it can be used in both hospital and home settings, without being limited by the application environment, and by using the AHP method to evaluate and rank the importance of each design element, overlooked design points can be discovered. The experimental results show that this finger training device significantly improves the recovery of finger function in stroke

patients and has advantages such as ease of use and practicality.

The research method of this article is based on the AHP method, which evaluates and ranks the importance of each design element to make the device design more reasonable and adequate. This method can provide a new idea and method for designing other similar rehabilitation devices to improve their application effectiveness and practicality.
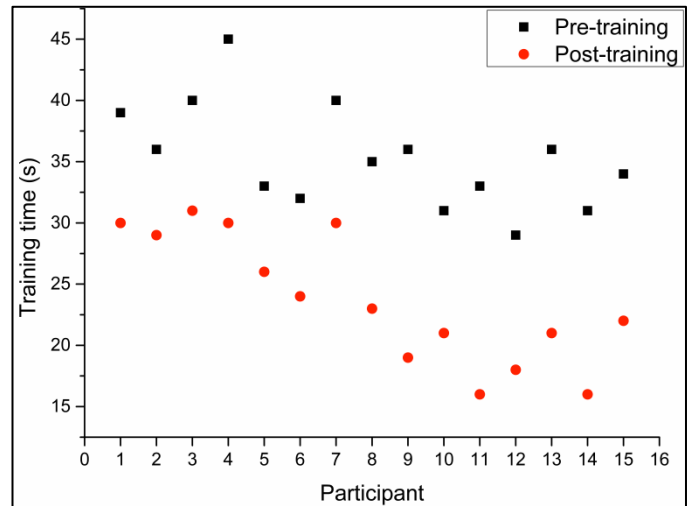


Fig. 9.    Comparison of the time taken to complete a session before and after two-handed training.

## VII. CONCLUSION

Through the research in this paper, we have successfully designed a stroke finger training device based on AHP. It can meet the exercise needs of finger operation on a computer, with active training being the focus. By using the AHP method to evaluate and rank the importance of each design element, overlooked design points can be discovered. The experimental results show that this finger training device significantly improves the recovery of finger function in participants and has advantages such as ease of use and practicality.

However, some things could be improved in this study. For example, the sample collection for the experiment mainly consisted of healthy subjects. In future clinical studies, it would be necessary to include more stroke patients as subjects to improve the reliability and persuasiveness of the experimental data. Additionally, the control module of the device can be further improved to enhance its intelligence and user experience. Future research can further explore this training device's application scope and effectiveness and combine it with other rehabilitation treatments to improve the rehabilitation outcomes for stroke patients. Furthermore, the design and functionality of the device can be further improved and refined to meet the needs of patients with different rehabilitation requirements.

## REFERENCES

[1]    X. Zhao, H. Chen, X. Dong, Q. Zou, X. Liang, J. Wu, and C. Wang, "Trends in stroke incidence in Nanshan district from 2010 to 2021," Preventive Medicine, vol. 35, no. 3, pp. 200-204, 2023, doi: 10.19485/j.cnki.issn2096-5087.2023.03.004.

[2] R. Zhang, W. Ji, L. Han, and L. Zhang, "Trends in incidence and mortality of stroke in Ningbo City from 2012 to 2021," Preventive Medicine, vol. 35, no. 3, pp. 224-228, 2023, doi: 10.19485/j.cnki.issn2096-5087.2023.03.009.

[3] W. Zhang, X. Qin, W. Li, Z. Ma, and J. Dong, "Analysis of the trends in the incidence of stroke in Lianyungang City from 2014 to 2020," Preventive Medicine, vol. 34, no. 9, pp. 932-936, 2022, doi: 10.19485/j.cnki.issn2096-5087.2022.09.014.

[4] T.J. Liang, "Research progress on rehabilitation treatment of upper limb dysfunction in stroke hemiplegia," Journal of Guangxi Medical University, vol. 35, no. 7, pp. 1026-1030, Jul. 2018. doi: 10.16190/j.cnki.45-1211/r.2018.07.03.

[5] P. Polygerinos, S. Lyne, Z. Wang, et al., "Towards a soft pneumatic glove for hand rehabilitation," 2013 IEEE/RSJ International Conference on Intelligent Robots and Systems, Tokyo, Japan, 2013, pp. 1512-1517, doi: 10.1109/IROS.2013.6696549.

[6] H.J. Wu, L.N. Wu, L. Li, et al., "Research Progress of Comprehensive Intervention of Hand Function Rehabilitation Robot for Stroke," Journal of Biomedical Engineering, vol. 36, no. 1, pp. 151-157, Feb. 2019, doi: 10.7507/1001-5515.201711024.

[7] N. Friedman, V. Chan, A. N. Reinkensmeyer, et al., "Retraining and assessing hand movement after stroke using the MusicGlove: comparison with conventional hand therapy and isometric grip training," Journal of neuroengineering and rehabilitation, vol. 11, pp. 76, Apr. 2014, doi:10.1186/1743-0003-11-76.

[8] N.J. Seo, M.L. Woodbury, L. Bonilha, et al. "TheraBracelet Stimulation During Task-Practice Therapy to Improve Upper Extremity Function After Stroke: A Pilot Randomized Controlled Study," Physical therapy, vol. 99, no. 3, pp. 319-328, 2019, doi: 10.1093/ptj/pzy143.

[9] R. G. Barelli, V. F. Avelino, and M. C. F. Castro, "STIMGRASP: A Home-Based Functional Electrical Stimulator for Grasp Restoration in Daily Activities," Sensors (Basel), vol. 23, no. 1, pp. 10, Dec. 2022, doi: 10.3390/s23010010.

[10] R. M. W. de Oliveira, "Neuroplasticity," Journal of Chemical Neuroanatomy, vol. 108, pp. 101822, 2020, doi: 10.1016/j.jchemneu.2019.101822.

[11] G. D. Lu, Q. Y. Zhang, N. An, et al., "Kinematic simulation analysis of hand rehabilitation robot based on ADAMS," Machine Design, vol. 37, no. 6, pp. 87-90, 2020.

[12] Y. W. Wang, P. L. Lu, S. F. Zheng, et al., "Design of a shape memory alloy-driven functional finger rehabilitation exoskeleton," Journal of Zhejiang University (Engineering Edition), vol. 54, no. 12, pp. 2340-2348, 2022, doi: 10.3785/j.issn.1008-973X.2022.12.015.

[13] Y. F. Fang and X. Guo, "A finger rehabilitation training device," Patent number CN 210197649 U, Dec. 2020.

[14] Y. L. Xie, Y. X. Yang, H. Jiang, et al., "Brain-machine interface-based training for improving upper extremity function after stroke: A meta-analysis of randomized controlled trials," Frontiers in Neuroscience, vol. 16, pp. 949575, 2022, doi: 10.3389/fnins.2022.949575.

[15] S. Feng, M. Tang, G. Huang, et al., "EMG biofeedback combined with rehabilitation training may be the best physical therapy for improving upper limb motor function and relieving pain in patients with the post-stroke shoulder-hand syndrome: A Bayesian network meta-analysis," Frontiers in Neurology, vol. 13, pp. 1056156, 2023, doi: 10.3389/fneur.2022.1056156.

[16] H. B. Wang, B. Yan, X. C. Wang, et al., "Design of end-traction finger rehabilitation robot and its flexibility control method," China Science and Technology Paper, vol. 15, no. 7, pp. 743-749, 2020.

[17] M. Li, J. Z. Chen, B. He, et al., "Motion planning and structural optimization of a multi-segment continuous structure hand functional rehabilitation exoskeleton," Journal of Xi'an Jiaotong University, vol. 53, no. 10, pp. 1-11, 2019.

[18] M. W. Zhong, Y. F. Feng, Z. M. Chen, et al., "Structural design and control system design of a progressive finger rehabilitation robot," Mechanical Design, vol. 39, no. 10, pp. 27-33, 2022.

[19] A. Abbasi Moshaii, M. Mohammadi Moghaddam, and V. Dehghan Niestanak, "Fuzzy sliding mode control of a wearable rehabilitation robot for wrist and finger," Industrial Robot: The International Journal of Robotics Research and Application, vol. 46, no. 6, pp. 839-850, 2019, doi: 10.1108/IR-05-2019-0118.

[20] X. Zhang, X. Mo, C. Li, et al., "A wearable master-slave rehabilitation robot based on an epidermal array electrode sleeve and multichannel electromyography network," Advanced Intelligent Systems, vol. 5, no. 3, pp. 2200313, 2023, doi: 10.1002/aisy.202200313.

[21] S. F. M. Toh, P. F. Chia, and K. N. K. Fong, "Effectiveness of home-based upper limb rehabilitation in stroke survivors: A systematic review and meta-analysis," Frontiers in Neurology, vol. 13, pp. 964196, 2022, doi: 10.3389/fneur.2022.964196.

[22] P. Langhorne, F. Coupar, and A. Pollock, "Motor recovery after stroke: A systematic review," The Lancet Neurology, vol. 8, no. 8, pp. 741-754, 2009, doi: 10.1016/S1474-4422(09)70150-4.

[23] S. H. Cauraugh and R. W. Summers, "Upper extremity rehabilitation in stroke: The importance of understanding motor control," Neurology Report, vol. 25, no. 2, pp. 55-60, 2001, doi: 10.1097/01253086-200125020-00003.

[24] J. H. Broeks, J. Lankhorst, and G. Rumping, "The long-term outcome of arm function after stroke: Results of a follow-up study," Disability and Rehabilitation, vol. 22, no. 6, pp. 261-264, 2000, doi: 10.1080/096382800406431.

[25] R. W. Bohannon, "Hand-grip dynamometry predicts future outcomes in aging adults," The Journal of Geriatric Physical Therapy, vol. 33, no. 1, pp. 3-10, 2010, doi: 10.1519/JPT.0b013e3181ceaa5a.

[26] M. M. Shaughnessy, P. A. Michael, and C. A. Siders, "Upper-extremity function and recovery in the acute phase poststroke," Journal of Neurologic Physical Therapy, vol. 28, no. 3, pp. 157-166, 2004, doi: 10.1097/01.NPT.0000140644.95819.4F.

[27] T. L. Saaty, "How to make a decision: The analytic hierarchy process," European Journal of Operational Research, vol. 48, no. 1, pp. 9-26, 1990, doi: 10.1016/0377-2217(90)90057-I.

[28] L. Xu and X. Chen, "A review of multi-criteria decision-making methods based on the analytic hierarchy process," International Journal of Information Technology & Decision Making, vol. 11, no. 02, pp. 445-472, 2012, doi: 10.1142/S021962201240006X.

[29] T. L. Saaty, "Fundamentals of decision making and priority theory with the analytic hierarchy process," RWS Publications, Pittsburgh, PA, USA, 2000.

[30] W. W. Chin, "The partial least squares approach to structural equation modeling," in Modern Methods for Business Research, G. A. Marcoulides, Ed. Mahwah, NJ: Lawrence Erlbaum Associates, 1998, pp. 295-336.

[31] X. Yang and Z. Zhang, "Design of bathroom products based on AHP hierarchical analysis method," Packaging Engineering, vol. 42, no. 4, pp. 144-147+153, 2021, doi: 10.19554/j.cnki.1001-3563.2021.04.019.

[32] Z. Liu and Z. Wang, "Research on intelligent charging pile design based on SAPAD-AHP method," Journal of Graphics, vol. 44, no. 2, pp. 380-388, 2023.

[33] Z. Wang and J. Xu, "Design and evaluation of agricultural special product packaging based on AHP and fuzzy model," Packaging Engineering, vol. 43, no. 6, pp. 213-219, 2022, doi: 10.19554/j.cnki.1001-3563.2022.06.028.

[34] A. Schlenker and T. Tichý, "A new approach to the evaluation of local muscular load while typing on a keyboard," Central European Journal of Public Health, vol. 25, no. 4, pp. 255-260, 2017, doi: 10.21101/cejph.a4824.

[35] M. L. Chang and C.-H. Shih, "Improving fine motor activities of people with disabilities by using the response-stimulation strategy with a standard keyboard," Research in Developmental Disabilities, vol. 35, no. 8, pp. 1863–1867, 2014. doi: 10.1016/j.ridd.2014.04.011.

[36] J. F. Soechting and M. Flanders, "Flexibility and repeatability of finger movements during typing: Analysis of multiple degrees of freedom," Journal of Computational Neuroscience, vol. 4, no. 1, pp. 29-46, 1997, doi: 10.1023/A:1008877207867.

[37] M. J. Bufton, R. W. Marklin, M. L. Nagurka, and G. G. Simoneau, "Effect of keyswitch design of desktop and notebook keyboards related to key stiffness and typing force," Ergonomics, vol. 49, no. 10, pp. 996-1012, 2006, doi: 10.1080/00140130600577437.

# A Blockchain-based Method Ensuring Integrity of Shared Data in a Distributed-Control Intersection Network

Mohamed El Ghazouani[1], Abdelouafi Ikidid[2], Charafeddine Ait Zaouiat[3],
Aziz Layla[4], Mohamed Lachgar[5], Latifa Er-Rajy[6]

ESIM, Polydisciplinary Faculty of Sidi Bennour, Chouaîb Doukkali University, El Jadida, Morocco[1, 3, 4]
Laboratory of System Analysis, Information Processing and Industrial Management,
EST Salé, Mohammed V University, Salé, Morocco[2]
LTI, National School of Applied Sciences, Chouaîb Doukkali University, El Jadida, Morocco[5]
Computer Science Department, Laboratory of Information Systems Engineering,
Cadi Ayyad University, Marrakesh, Morocco[6]

*Abstract*—In modern urban transportation systems, the efficient management of traffic intersections is crucial to ensure smooth traffic flow and reduce congestion. Distributed-control intersection networks, where control decisions are made collaboratively by multiple entities, offer promising solutions. However, maintaining the security and the integrity of shared data among these entities poses significant challenges, including the risk of data tampering and unauthorized modifications. This paper proposes a novel approach that leverages blockchain technology to address these integrity concerns based on intelligent agents. By utilizing the decentralized and transparent nature of blockchain, our method ensures the authenticity and immutability of shared data within the distributed-control intersection network. The paper presents a detailed architecture, highlighting the integration of blockchain into the existing infrastructure, and discusses the benefits of this approach in enhancing data integrity, trust, and overall system reliability. Through a case study and simulation results, the proposed approach demonstrates its effectiveness in maintaining the integrity of shared data, thereby contributing to the advancement of secure and efficient traffic management systems.

*Keywords*—*Security; data integrity; blockchain; distributed system; congestion; intelligent agent*

## I. INTRODUCTION

In the face of rapidly expanding urban populations, the efficient management of traffic intersections has emerged as a critical aspect of modern urban transportation systems [1]. Traditional traffic control mechanisms, reliant on centralized decision-making, struggle to accommodate the dynamic demands of increasingly congested road networks. This has spurred the development of distributed-control intersection networks, which offer a more adaptive and responsive approach to traffic management. In these networks, control decisions are distributed across multiple entities, allowing real-time adjustments based on traffic conditions, thereby improving overall traffic flow and reducing congestion [2].

The advantages of distributed-control intersection networks are evident, but they bring forth new challenges, particularly concerning the integrity of shared data among the participating entities. The accuracy and authenticity of data exchanged within these networks are pivotal for their successful operation. Compromised or tampered data can lead to erroneous control decisions, potentially resulting in accidents, increased congestion, and even system-wide failures [3]. Hence, the establishment of a robust method to ensure data integrity is crucial.

Blockchain technology continues to evolve, with new consensus mechanisms, scalability solutions, and use cases being developed. Understanding these fundamentals is crucial for grasping the potential impact of blockchain on various industries [4].

This paper introduces a novel approach that leverages blockchain technology to address the integrity concerns in distributed-control intersection networks. Blockchain has emerged as a powerful tool for addressing data integrity concerns in distributed and decentralized systems. Initially introduced as the foundational technology underpinning cryptocurrencies like Bitcoin [5], blockchain has evolved to demonstrate its applicability beyond financial use cases. Its core features, including decentralized data management, immutability, and cryptographic security, make it an ideal candidate for ensuring data integrity in complex systems, such as distributed-control intersection networks.

By presenting a comprehensive analysis of the proposed methodology, backed by a practical case study and simulation results, this paper aims to contribute to the development of robust and trustworthy distributed-control intersection networks that can effectively address the challenges of modern urban transportation. The organization of this paper is as stated below: Section II outlines the related works. The various blockchain fundamentals are discussed in Section III. Section IV describes our proposed methodology. Section V includes the simulation results and discussion. Lastly, a conclusion is outlined in Section VI.

## II. RELATED WORKS

In recent years, the integration of blockchain technology into various domains has garnered significant attention due to

its potential to enhance security, and decentralization. In the context of distributed-control intersection networks, where efficient traffic management is crucial, the utilization of blockchain for ensuring the integrity of shared data has emerged as a promising avenue. Several related works have explored similar themes and provided insights into the application of blockchain in distributed-control systems and intersection networks.

Traditional static control systems may fail to handle emergency situations due to traffic jams. As a solution, Wireless Sensor Networks (WSNs) have gained attention for their ability to detect traffic and mitigate road congestion. K. Nellore and G. P. Hancke [6] have extensively explored traffic management systems that employ WSNs to prevent congestion, prioritize emergency vehicles, and reduce the Average Waiting Time (AWT) at intersections. They offered a comprehensive survey of current urban traffic management strategies, particularly those focused on priority-based signaling, congestion reduction, and improving vehicle AWT. Z. Yang et al. [7] introduced a promising approach to address trust issues in vehicular networks through the use of blockchain and a decentralized trust management system. They introduced a solution to enhance the trustworthiness of messages exchanged among vehicles in vehicular networks, considering the challenging non-trusted environment. A. Daeichian and A. Haghani [8] employed a combination of fuzzy Q-learning (QL) and agent technologies to create a traffic light control framework. Each individual agent engages with neighboring agents, receiving rewards for their decisions. The control choices are determined based on the input of vehicle numbers to schedule the duration of the green traffic light phase. The primary objective is to optimize the reward and minimize the average delay time. A. Ikidid et al. [9] presented a novel approach to address traffic management challenges in Moroccan cities, with a focus on promoting emergency vehicle access and encouraging collective transportation modes. The proposed control system operates at signalized intersections with priority links in urban environments. This system combines multi-agent technology and fuzzy logic to effectively regulate traffic flows.

On the other hand, the significance of data integrity in distributed-control systems has prompted research into various methodologies. T. Rauter [10] emphasized the significance of maintaining the integrity of the entire distributed control system. He categorized specific properties that enable the verification and proof of integrity for various subsystems within the system. Q. Kong et al. [11] introduced a novel, efficient, and location privacy-preserving data sharing scheme with collusion resistance within the Internet of Vehicles (IoV) context. Furthermore, blockchain's decentralized nature has been leveraged for secure data sharing across multiple parties. G. P. Joshi et al. [12] proposed a blockchain-based method for secure and privacy-preserving data sharing in vehicular networks. Although not specific to intersection networks, this work highlights the potential of blockchain in ensuring data integrity and security in vehicular environments. J. Cui et al. [13] proposed an innovative solution utilizing consortium blockchain technology to enable traceable and anonymous vehicle-to-vehicle (V2V) data sharing. It addresses critical issues in current vehicular networks, including data privacy, security, and trust, while also capitalizing on the advantages of emerging technologies such as blockchain and 5G. S. Kudva et al. [14] proposed an innovative approach to selecting miner nodes in vehicular blockchain applications. The proposed method, called the "Proof of Driving" protocol, associates "driving coins" with vehicle features, such as distance traveled, to enhance the randomness in selecting miner nodes. In [15], S. A. Bagloee et al. discussed how a blockchain-based platform can facilitate the deployment of tradable mobility permits (TMP), along with related benefits like dynamic toll pricing, emergency vehicle priority, heavy truck platooning, and connected vehicles. I. M. Varma and N. Kumar introduced the convergence of Internet of Vehicles (IoV) and Software-Defined Networking (SDN), enhanced by blockchain technology, that offers a promising solution to address the complex challenges of vehicular networks, providing improved transportation, security, and network management while also presenting opportunities for further research and development [16]. A set of approaches and protocols have been proposed to determine the feasibility of using blockchain for traffic data security [17] and [18].

While existing related works provide valuable insights into blockchain's potential in distributed-control intersection networks, certain challenges remain unexplored. Integrity of shared data is a crucial factor in real-time traffic management scenarios. Additionally, the interoperability between blockchain and existing traffic infrastructure requires further investigation. The research landscape regarding blockchain's role in ensuring the integrity of shared data in distributed-control intersection networks is steadily growing. By building upon the foundation laid by previous related works, this study aims to contribute to the understanding of how blockchain can effectively enhance data integrity and efficiency in traffic management systems.

## III. BLOCKCHAIN FUNDAMENTALS

Blockchain is a revolutionary technology that serves as the foundation for cryptocurrencies like Bitcoin and has far-reaching applications beyond digital currencies. At its core, blockchain is a decentralized and distributed digital ledger that records transactions in a secure, transparent, and immutable manner. Fig. 1 illustrates the benefits that arise from the adoption of blockchain.
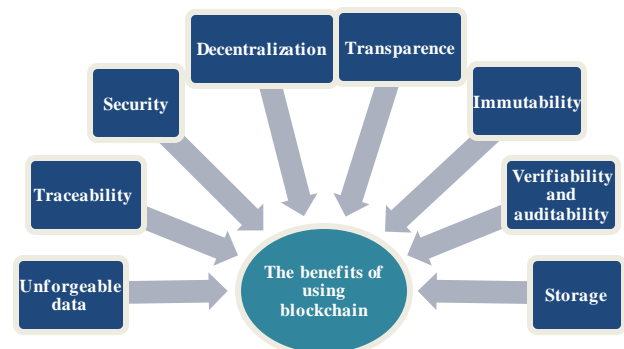


Fig. 1. The benefits of using blockchain.

Blockchain technology has several features that make it highly suitable for ensuring data integrity in a distributed-control intersection network. Here are some key features:

- Decentralization: Blockchain operates on a decentralized network of nodes, where each node stores a copy of the entire blockchain. In a distributed-control intersection network, this decentralization ensures that no single entity has control over the entire system. This feature reduces the risk of a single point of failure and enhances the network's resilience.

- Immutability: Once data is recorded on the blockchain, it is extremely difficult to alter or delete [19]. This immutability ensures that the historical data related to traffic control decisions and intersection activities remain tamper-proof, providing a reliable audit trail.

- Transparency: All participants in the network can view the data recorded on the blockchain [20]. In the context of a distributed-control intersection network, this transparency ensures that all stakeholders, including traffic authorities, city planners, and even the public, can access relevant data, promoting trust and accountability.

- Consensus Mechanisms: Blockchain networks use consensus mechanisms to validate transactions or data entries. This ensures that all nodes in the network agree on the state of the blockchain. Consensus mechanisms such as Proof of Work (PoW) [21] or Proof of Stake (PoS) [22] can be used to ensure that intersection control decisions are agreed upon by the network, minimizing the risk of unauthorized changes.

- Data Integrity: Blockchain can be used to create a secure and tamper-evident record of intersection control decisions, traffic data, and other relevant information. This ensures that the data remains consistent and reliable [23], which is crucial for maintaining the efficiency and safety of the intersection network.

- Smart Contracts: Smart contracts are self-executing contracts with the terms directly written into code [24]. In a distributed-control intersection network, smart contracts could automate and enforce specific rules and conditions, such as prioritizing emergency vehicles or optimizing traffic flow based on predefined criteria.

- Security: Blockchain networks use cryptographic techniques to secure data [25]. This enhances the security of the intersection network, protecting it from unauthorized access, data breaches, and cyberattacks.

- Auditability: Every transaction or data entry on the blockchain is traceable. This auditability ensures that all changes to the intersection network's data can be tracked back to their source, providing accountability and facilitating investigations when necessary.

By leveraging these features, a blockchain-based approach can enhance the integrity of shared data in a distributed-control intersection network, reducing the risk of data manipulation, promoting trust among network participants, and contributing to more secure and efficient traffic management systems.

## IV. PROPOSED METHODOLOGY

### A. Problem Modeling

A distributed control system (DCS) for light control intersections is a sophisticated networked system designed to manage traffic flow and optimize vehicle and pedestrian movement at intersections. It utilizes advanced technologies and algorithms to efficiently control traffic signals, ensure safety, and minimize congestion. An intersection network consists of multiple intersections that are strategically connected to form a network. These intersections can vary in size and complexity, ranging from simple crossroads to multi-lane junctions. Fig. 2 shows an overview of an intersection network with nine intersections, each intersection has four two-way roads.

The DCS is functionally and spatially distributed. Every intersection is viewed as a network sub-section and controlled by a community named Intersection Control Group (ICG) and consists of a group of autonomous, cooperative, and intelligent agents. Each community acts locally according to its data and communicates with others to coordinate actions. This system promotes flexibility, resilience and efficiency by enabling individual components to contribute to an overall solution without depending on a single central authority. Communication in these distributed systems involves the exchange of information between different interconnected autonomous communities. These communities often communicate via local or wide-area networks, which introduce a security challenge.

The control of each signalized intersection is performed by an ICG, which defines the signal plan. This plan is designed to optimize phase layout while adapting to the constantly changing intersection environment, with control of the entire intersection network being fully distributed and achieved through the collective capacity, communication, and coordination of the ICGs.
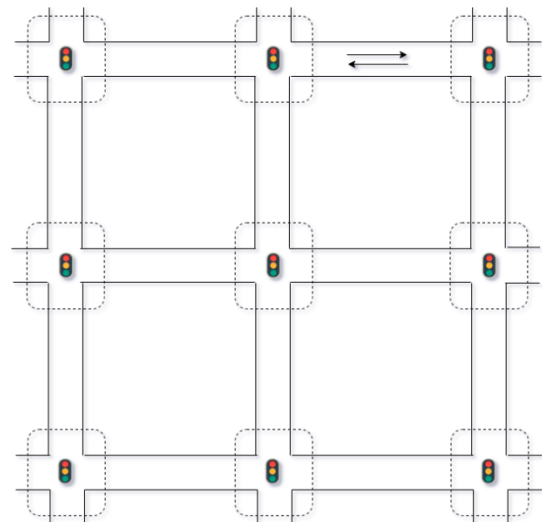


Fig. 2. Signaled intersection network.
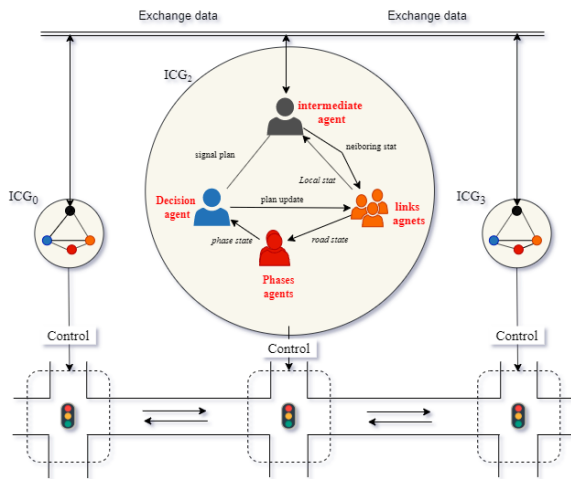
Fig. 3. Overview of distributed-control intersection networks.

Fig. 3 presents an overview of distributed Urban Traffic management System. It generally involves of a set of control groups, each control group consists of:

- Links agents: An agent represents each link, a "link" refers to a specific segment of road that connects two distinct points. An agent link is assigned to supervise each incoming link, with the aim of consistently and promptly monitoring the link state. These specific agents have a limited, local perspective of the environment. In order to maintain system simplicity, no agent is granted a comprehensive overview of the entire network, thereby reducing overall complexity. The goal of this agent is to provide the link state presented by the concentration D. The concentration of a particular road at a given point is the number N of vehicles present between p and p+Δp at an instant t, relative to the length of the section of lane (Eq. 1). The concept of vehicular concentration refers to the density of vehicles occupying a specific section of a road at a given point in time.

$$D_{\Delta t}(p) = D(p, t \rightarrow t + \Delta t) = \frac{V}{\Delta t} \qquad (1)$$

- Phase agents: Two distinct agents are employed to oversee phases within an intersection. The Activated Phase Agent handles the active phase, while the Inactive Phase Agent manages phases that are not currently active. The goal of this agent is to provide the phase state.

- Decision agent: The decision agent is the central element of the system architecture, responsible for updating the signal plan according to changes in the environment. This decision-making process is executed collaboratively to prevent isolated optimizations.

- Intermediate agent: The role of the intermediate agent is to establish coordination with the neighboring control group. It acts as a communication interface agent for the intersection control group and mediating external communications. This agent facilitates the exchange of

incoming link states with intermediate agents in neighboring control groups.

Ensuring the integrity of communications poses significant challenges in this type of system. As data passes through different nodes and networks to reach the control group, it is susceptible to corruption, interception and unauthorized access

### B. Overview of our Proposed System Model

We have seen in our earlier discussions the necessity to apply a new approach that can enhance the integrity of shared data in a distributed-control intersection network, reducing the risk of data manipulation, promoting trust among network participants, and contributing to more secure and efficient traffic management systems. A decentralized network in our model mainly includes several intersections that communicate with each other by sharing information of link state. Hence, design goal of our work is to make the public blockchain usable in the distributed-control intersection networks by storing the local link state of each intersection, which will guarantee the integrity of the data exchanged between the different intersections. Fig. 4 illustrates how different components of our proposal are connected. Detailed descriptions of the proposed system are given in the following:

- Creating blocks: In our model, each intersection system will have an associated blockchain database. All the records of link states are considered as transactions that are validated by the ICG and finally added into immutable blocks of the blockchain. The block contains the link state data, the merkle root, previous block hash, block size and timestamp. Timestamps in the blockchain ensure a chronological record of data.

- Calculating signals plan: Each ICG refers to the neighboring ICG blockchain in order to retrieve their link states that permit to calculate the signals plan of the current intersection.

- ICG: To maintain data integrity of shared link state, each ICG calculates link state then stores it in a new block within a specific blockchain related to the intersection. In case of an intersection system failure, the ICG can then send a data query to ask for historical link state, in a particular moment, from the neighboring ICG's Blockchain.

- ICG Blockchain: each ICG Blockchain maintains the blocks corresponding to the different calculated link states. The blockchain records the history of intersection link states, therefore the use of the blockchain is essential in the event of an intersection system failure, so that the new signals plan of the intersection can be calculated based on the link states previously stored in the blockchain, thereby streamlining the decision-making process in the distributed-control system.

For the intersections, each generation of a link state is treated as a transaction on the blockchain. Every link state data is hashed and added to the blockchain, creating an immutable record. Hashes serve as a fingerprint of the data, making it easy to detect any modifications.
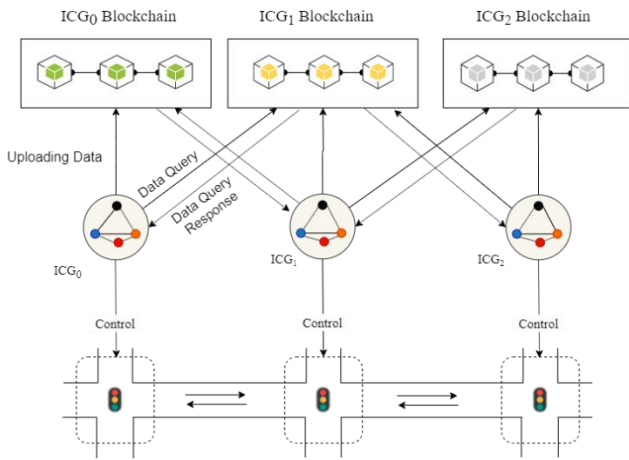
Fig. 4. Overview of blockchain based distributed-control intersection networks.

## C. Data Integrity Auditing for Distributed-Control Intersection Networks

Shared data integrity auditing for distributed-control intersection networks using blockchain is a concept that applies the principles of blockchain technology to ensure the accuracy and reliability of data in intersection networks that employ a distributed control approach. In such networks, multiple intersections or traffic management components collaborate to optimize traffic flow and enhance transportation efficiency. Blockchain can play a role in storing the exchanged data and maintaining its integrity among these distributed components.

Auditors (ICGs) can verify the integrity of data by comparing the expected data with the historical records on the blockchain. Automated audits can be performed to constantly monitor and validate data against predefined criteria. All ICGs can independently verify the accuracy of data, promoting trust and transparency within the intersection network.

The provided pseudo-code outlines an algorithm for conducting data integrity auditing according to our proposal. This process ensures the accuracy and consistency of data stored in the blockchain, mitigating potential errors or tampering.

These are the steps of the algorithm:

- The algorithm begins by checking if the target block index is within valid bounds. If not, it returns an error message indicating an invalid index.

- After that, it retrieves the target block from the blockchain using the provided index.

- Then, it calculates the hash of the expected data and compares it with the stored hash of the link state data within the target block. If they do not match, it concludes that the data integrity audit has failed.

- Next, the algorithm iterates through the blockchain starting from the block after the target block. It retrieves each block and its corresponding previous block to verify the chain's integrity. If the PreviousHash of a block does not match the BlockHash of its previous

block, the algorithm concludes that the blockchain integrity has been compromised.

- For each block (except the target block), it calculates the hash of the link state data and compares it to the stored hash in the block. If they do not match, the data integrity audit fails.

- If all checks pass, the data integrity audit is successful.

| Algorithm: Data Integrity Auditing |
|---|
| **Input**: - Blockchain: The blockchain to be audited<br> - Target_Block_Index: The index of the Target_Block to audit<br> - Expected_Data: The Expected_Data for the Target_Block |
| **Output**: - Audit_Result: Whether the data integrity audit passed or failed |
| **1: Procedure:** PerformDataIntegrityAudit(Blockchain, Target_Block_Index, Expected_Data):<br>**2:** **If** Target_Block_Index < 0 or Target_Block_Index >= Length(Blockchain):<br>**3:** **Return** "*Invalid Target_Block_Index*"<br>**4:** **End If**<br>**5:**<br>**6:** Target_Block = GetBlockByIndex(Blockchain, Target_Block_Index)<br>**7:**<br>**8:** **If** HashFunction(Expected_Data) != Target_Block.Link_state Data Hash:<br>**9:** **Return** "*Data integrity audit failed*"<br>**10:** **End If**<br>**11:**<br>**12:** **For each** block in Blockchain from Target_Block_Index + 1 to last block:<br>**13:** Previous Block = GetBlockByIndex(Blockchain, block.Index - 1)<br>**14:** **If** block.PreviousHash != Previous Block.BlockHash:<br>**15:** Return "*Blockchain integrity compromised*"<br>**16:** **End If**<br>**17:**<br>**18:** **If** block.Index == Target_Block_Index:<br>**19:** ***Continue***<br>**20:** **End If**<br>**21:**<br>**22:** **If** HashFunction(block.Link_state Data) != block.Link_state Data Hash:<br>**23:** Return "*Data integrity audit failed*"<br>**24:** **End If**<br>**25:** **End For**<br>**26:** Return "*Data integrity audit passed*" |
| **27: Main:**<br>**28:** Read the Blockchain<br>**29:** Read Target_Block_Index<br>**30:** Read Expected_Data<br>**31:** *Audit_Result* = PerformDataIntegrityAudit(Blockchain, Target_Block_Index, Expected_Data)<br>**32:** Print *Audit_Result*<br>**33: End Main** |

This algorithm ensures data integrity auditing within a blockchain by verifying the consistency of data in the target block and checking the integrity of the entire blockchain. If any discrepancies are found during this audit process, it indicates potential errors or tampering within the blockchain, thus helping to maintain the reliability and trustworthiness of the data stored in the system.

Implementing data integrity auditing for distributed-control intersection networks using blockchain can offer several benefits:

- Data Consistency: Blockchain's immutability ensures that data remains consistent and trustworthy across all components.

- Enhanced Security: Blockchain's cryptographic mechanisms make data tampering extremely difficult.

- Interoperability: Different components can work together while relying on a common source of truth provided by the blockchain.

- Real-time Auditing: Auditing processes can be automated and performed in real-time, minimizing the risk of errors going undetected.

## V. SIMULATION RESULTS AND DISCUSSION

In this section, we provide a detailed overview of the implementation of our proposed blockchain-based method for ensuring the integrity of shared data in a distributed-control intersection network. The implementation was carried out using a combination of software tools, programming languages, and blockchain frameworks.

As shown in Fig. 5, our implementation follows a layered architecture, comprising the following components:

*1) Simulation of urban traffic:* To simulate various traffic scenarios we use AnyLogic software [26]. AnyLogic is a java-based simulation software used for modeling and analyzing complex systems, including urban traffic.

*2) Distributed control system:* To develop the distributed control system we use agent-based modeling feature in AnyLogic, which allows to define the agent types, properties, and behaviors.

*3) Blockchain network:* We utilized the Ethereum blockchain due to its established infrastructure and support for smart contracts. The blockchain network stores transaction data, including link state, network meta-data, and validation mechanisms.

*4) Results extraction:* The results extraction phase involves collecting data generated from simulation runs. This data is captured at designated points within the model. To evaluate our approach (method-2), we will compare it with a distributed control system without blockchain (method-1).
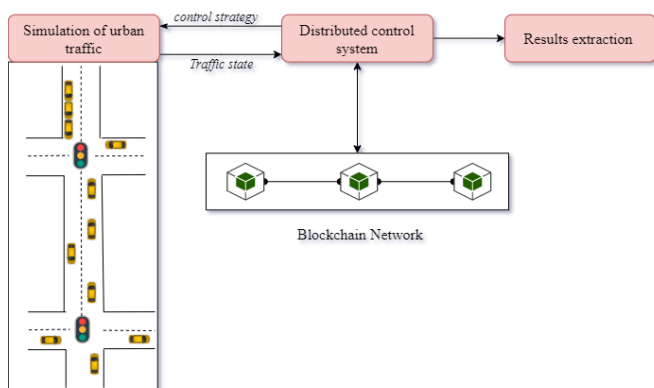


Fig. 5. Process simulation.

We will use four scenarios that collectively help assess the blockchain-based method's effectiveness across varying levels of communication network state and in the face of system failure.

- Scenario 1: Low Network Communication state: In this scenario, the network experiences a situation of low communication bandwidth and high latency. The data exchanges between IGCs, agents, and the blockchain nodes are slow and sporadic. Transactions take longer to propagate through the network, causing delays in data integrity verification and confirmation. This scenario tests the resilience of the blockchain-based method under adverse network conditions and assesses its ability to process and verify transactions with limited bandwidth and high latency. Without a blockchain, a low network communication state might lead to difficulties in transaction verification and data sharing.

- Scenario 2: Medium Network Communication state: Under medium network communication conditions, the network is relatively stable with moderate communication bandwidth and latency. Data exchanges occur at a reasonable pace, allowing transactions to propagate and confirm without significant delays. This scenario aims to evaluate the blockchain's performance under typical operational network conditions, assessing whether the method can efficiently maintain data integrity and transaction consistency. Without blockchain, medium network communication might be more manageable than in a low state, but challenges like data consistency and reliance on intermediaries for verification could arise.

- Scenario 3: High Network Communication state: In a high network communication scenario, the network experiences heavy congestion and high communication demands. Data exchanges between ICG, agents, and blockchain nodes are frequent and rapid. This situation challenges the system's capacity to handle a large volume of transactions without compromising its integrity. The blockchain's ability to handle high transaction throughput and maintain data consistency is assessed, along with its ability to handle potential network bottlenecks. In a high network communication state, non-blockchain systems may struggle to maintain data consistency and handle the influx of real-time transactions.

- Scenario 4: System Failure: In the event of network communication failure, a blockchain system can continue to function locally on ICG. Once communication is restored, the system can automatically synchronize and reconcile the distributed ledger, ensuring data integrity and minimizing the risk of data loss. Network communication failure in a non-blockchain system could lead to data discrepancies, conflicts, and potentially control system failure.

By simulating and analyzing these scenarios involving different network communication state (see Fig. 6) we can gain a comprehensive understanding of how the blockchain-based method performs under various levels of network stability. In summary, blockchain technology offers advantages like decentralization and stability in various network communication scenarios. However, its effectiveness depends on factors such as the specific use case, network

conditions, and the degree of decentralization required. Non-blockchain systems might suffice for certain situations.
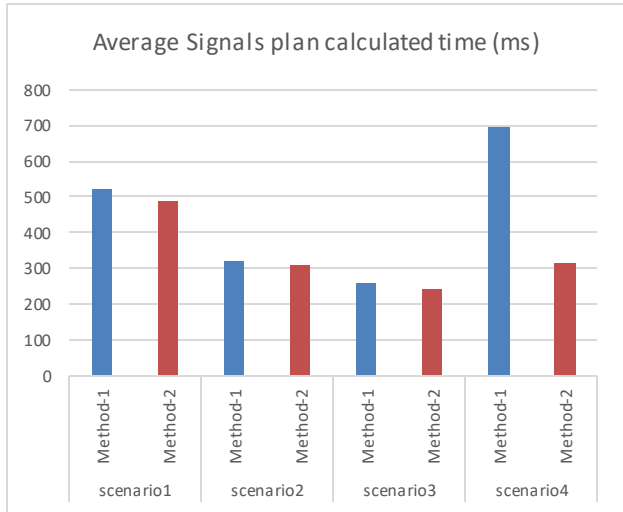


Fig. 6.   Average signals plan calculated time.

In the following section, we explore a series of diverse scenarios that cover different urban traffic contexts and situations. These scenarios have been carefully selected to provide relevant examples of concrete traffic situations.

Scenario 1: Low Traffic Condition: In this scenario, the intersection network experiences a period of low traffic. The number of vehicles approaching the intersection is minimal, resulting in infrequent data updates and interactions.

Scenario 2: Medium Traffic Condition: In a medium traffic scenario, the intersection network encounters a moderate volume of vehicles during peak hours.

Scenario 3: High Traffic Condition: During high traffic conditions, the intersection network experiences heavy congestion with a significant influx of vehicles from various directions. This scenario pushes the limits of the system's capacity.

By simulating and analyzing these scenarios, we can gain insights into the system's strengths, weaknesses, and areas for improvement, thereby refining the control of distributed intersection network under a range of conditions.

Fig. 7 presents the average intersection throughput in PVU (Private Vehicle Unit) per hour. The graph shows that the effectiveness of blockchain in ameliorating average intersection throughput depends on congestion levels. While blockchain may not have a direct impact on the low congestion level, it could enhance the average intersection throughput in the medium and high traffic conditions by improving data access speed, collaboration, and coordination among various intersections, potentially contributing to more efficient traffic management and better throughput over time.

As shown in Fig. 8 the response latency of both methods follows a linear trend as the level of congestion increases. The proposed system achieves a latency between 1.22 and 1.83, while the traditional system achieves a latency between 1.32 and 1.95.
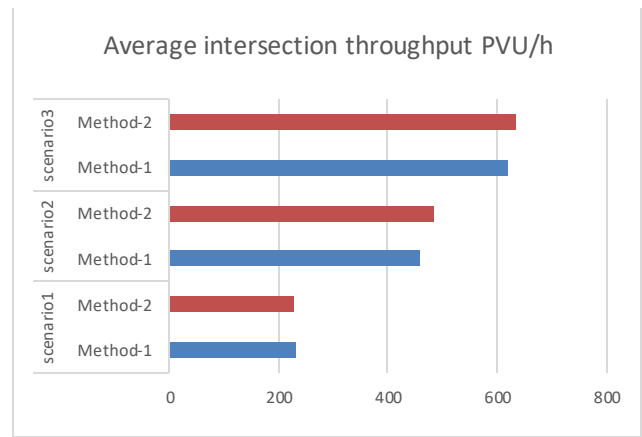


Fig. 7.   Average intersection throughput.
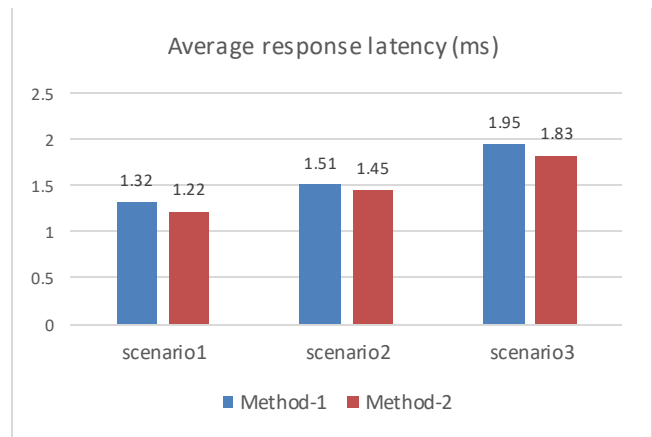


Fig. 8.   Average response latency.

Table I shows a comparison of security features between centralized, decentralized and blockchain-based systems:

TABLE I.      SECURITY FEATURES COMPARISON BETWEEN CENTRALIZED, DECENTRALIZED AND BLOCKCHAIN-BASED SYSTEM

|  | Centralized-based system | Decentralized-based system | Blockchain-based system |
|---|---|---|---|
| Decentralization | - | ++ | ++ |
| Traceability | - | - | ++ |
| Data integrity | - | + | ++ |
| Data availability | - | + | ++ |
| Verifiability and auditability | - | + | ++ |
| Immutability | - | + | ++ |
| Transparency | - | + | ++ |

Centralized systems can compromise data integrity if controlled by a single entity with malicious intent. Decentralized systems mitigate this risk by requiring consensus, and blockchain-based systems, with cryptographic verification and immutability, offer the highest assurance of data integrity. Furthermore, centralized systems' availability hinges on the central entity's stability, which can lead to disruptions. Decentralized systems, sharing data across nodes, increase availability, while blockchain-based systems exhibit

resilience, even when ICGs go offline, ensuring continuous data availability.

In summary, centralized systems might compromise security, whereas decentralized and blockchain-based systems enhance security through decentralization, data integrity, availability, auditability, immutability, and transparency. While each approach has its strengths and limitations, blockchain-based systems exhibit comprehensive security features, making them particularly well suited for applications where trust and security are paramount.

## VI. CONCLUSION

In conclusion, the research presented in this paper demonstrates the significant potential of utilizing blockchain technology to enhance the integrity and efficiency of shared data within a distributed-control intersection network. The implementation of a blockchain-based method has been shown to address the challenges associated with data integrity, trust, and transparency in this critical context. By leveraging the decentralized and immutable nature of blockchain, the proposed approach offers a robust solution for ensuring the authenticity and consistency of data exchanged among various intersection nodes.

The results of our experiments indicate that the blockchain-based method not only enhances the overall security posture of the intersection network but also contributes to the efficient management of the road traffic, reducing the risk of unauthorized modifications and data tampering. The blockchain records the history of intersection link states, therefore the use of the blockchain is essential in the event of an intersection system failure, so that the new signals plan of the intersection can be calculated based on the data previously stored in the blokchain, thereby streamlining the decision-making process in the distributed-control system.

It is worth noting that while this paper primarily focuses on the application of blockchain in a distributed-control intersection network, the concepts and insights presented herein have broader implications for other decentralized and data-sensitive systems. Future research could explore scalability and performance optimization, as well as real-world deployment and integration of the proposed solution. As the adoption of blockchain technology continues to expand, the findings of this study contribute to the advancement of secure and trustworthy data sharing in distributed systems, paving the way for safer and more efficient urban traffic management and beyond.

## REFERENCES

[1] M. Obaidat, M. Khodjaeva, J. Holst, and M. Ben Zid, "Security and privacy challenges in vehicular Ad Hoc networks," Connect. Veh. Internet Things Concepts, Technol. Fram. IoV, pp. 223–251, Jan. 2020, doi: 10.1007/978-3-030-36167-9_9/COVER.

[2] J. A. Guzman, G. Pizarro, and F. Nunez, "A Reinforcement Learning-Based Distributed Control Scheme for Cooperative Intersection Traffic Control," IEEE Access, vol. 11, pp. 57037–57045, 2023, doi: 10.1109/ACCESS.2023.3283218.

[3] A. Ikidid, M. El Ghazouani, Y. El Khanboubi, C. A. Zaouiat, A. El Fazziki, and M. Sadgal, "A New Approach to Intelligent-Oriented Analysis and Design of Urban Traffic Control: Case of a Traffic Light,"

[4] M. Javaid, A. Haleem, R. Pratap Singh, S. Khan, and R. Suman, "Blockchain technology applications for Industry 4.0: A literature-based review," Blockchain Res. Appl., vol. 2, no. 4, p. 100027, Dec. 2021, doi: 10.1016/J.BCRA.2021.100027.

[5] N. Satoshi and S. Nakamoto, "Bitcoin: A Peer-to-Peer Electronic cash system," Bitcoin, 2008, doi: 10.1007/s10838-008-9062-0.

[6] K. Nellore and G. P. Hancke, "A survey on urban traffic management system using wireless sensor networks," Sensors (Switzerland), vol. 16, no. 2, 2016, doi: 10.3390/s16020157.

[7] Z. Yang, K. Yang, L. Lei, K. Zheng, and V. C. M. Leung, "Blockchain-based decentralized trust management in vehicular networks," IEEE Internet Things J., vol. 6, no. 2, pp. 1495–1505, 2019, doi: 10.1109/JIOT.2018.2836144.

[8] A. Daeichian and A. Haghani, "Fuzzy Q-Learning-Based Multi-agent System for Intelligent Traffic Control by a Game Theory Approach," Arab. J. Sci. Eng., vol. 43, no. 6, pp. 3241–3247, Jun. 2018, doi: 10.1007/S13369-017-3018-9/METRICS.

[9] A. Ikidid, A. El Fazziki, and M. Sadgal, "A fuzzy logic supported multi-agent system for urban traffic and priority link control," J. Univers. Comput. Sci., vol. 27, no. 10, pp. 1026–1045, 2021, doi: 10.3897/jucs.69750.

[10] T. Rauter, "Integrity of Distributed Control Systems," Student Forum Int. Conf. Dependable Syst. Networks, pp. 1–4, 2016.

[11] Q. Kong, R. Lu, M. Ma, and H. Bao, "A privacy-preserving sensory data sharing scheme in Internet of Vehicles," Futur. Gener. Comput. Syst., vol. 92, pp. 644–655, 2019, doi: 10.1016/j.future.2017.12.003.

[12] G. P. Joshi, E. Perumal, K. Shankar, U. Tariq, T. Ahmad, and A. Ibrahim, "Toward blockchain-enabled privacy-preserving data transmission in cluster-based vehicular networks," Electron., vol. 9, no. 9, pp. 1–15, 2020, doi: 10.3390/electronics9091358.

[13] J. Cui, F. Ouyang, Z. Ying, L. Wei, and H. Zhong, "Secure and Efficient Data Sharing Among Vehicles Based on Consortium Blockchain," IEEE Trans. Intell. Transp. Syst., vol. 23, no. 7, pp. 8857–8867, 2022, doi: 10.1109/TITS.2021.3086976.

[14] S. Kudva, S. Badsha, S. Sengupta, I. Khalil, and A. Zomaya, "Towards secure and practical consensus for blockchain based VANET," Inf. Sci. (Ny)., vol. 545, pp. 170–187, 2021, doi: 10.1016/j.ins.2020.07.060.

[15] S. Asadi Bagloee, M. Tavana, G. Withers, M. Patriksson, and M. Asadi, "Tradable mobility permit with Bitcoin and Ethereum – A Blockchain application in transportation," Internet of Things, vol. 8, p. 100103, Dec. 2019, doi: 10.1016/J.IOT.2019.100103.

[16] I. M. Varma and N. Kumar, "A comprehensive survey on SDN and blockchain-based secure vehicular networks," Veh. Commun., vol. 44, p. 100663, Dec. 2023, doi: 10.1016/J.VEHCOM.2023.100663.

[17] M. Cebe, E. Erdin, K. Akkaya, H. Aksu, and S. Uluagac, "Block4Forensic: An Integrated Lightweight Blockchain Framework for Forensics Applications of Connected Vehicles," IEEE Commun. Mag., vol. 56, no. 10, pp. 50–57, Oct. 2018, doi: 10.1109/MCOM.2018.1800137.

[18] P. M. Dhulavvagol, V. H. Bhajantri, and S. G. Totad, "Blockchain Ethereum Clients Performance Analysis Considering E-Voting Application," Procedia Comput. Sci., vol. 167, pp. 2506–2515, Jan. 2020, doi: 10.1016/J.PROCS.2020.03.303.

[19] U. Tariq, A. Ibrahim, T. Ahmad, Y. Bouteraa, and A. Elmogy, "Blockchain in internet-of-things: a necessity framework for security, reliability, transparency, immutability and liability," IET Commun., vol. 13, no. 19, pp. 3187–3192, Dec. 2019, doi: 10.1049/IET-COM.2019.0194.

[20] J. Sedlmeir, J. Lautenschlager, G. Fridgen, and N. Urbach, "The transparency challenge of blockchain in organizations," Electron. Mark., vol. 32, no. 3, pp. 1779–1794, 2022, doi: 10.1007/s12525-022-00536-0.

[21] C. Schinckus, "Proof-of-work based blockchain technology and Anthropocene: An undermined situation?," Renew. Sustain. Energy Rev., vol. 152, p. 111682, Dec. 2021, doi: 10.1016/J.RSER.2021.111682.

[22] M. Wendl, M. H. Doan, and R. Sassen, "The environmental impact of cryptocurrencies using proof of work and proof of stake consensus algorithms: A systematic review," J. Environ. Manage., vol. 326, p. 116530, Jan. 2023, doi: 10.1016/J.JENVMAN.2022.116530.

[23] H. Han, S. Fei, Z. Yan, and X. Zhou, "A survey on blockchain-based integrity auditing for cloud data," Digit. Commun. Networks, vol. 8, no. 5, pp. 591–603, Oct. 2022, doi: 10.1016/J.DCAN.2022.04.036.

[24] S. N. Khan, F. Loukil, C. Ghedira-Guegan, E. Benkhelifa, and A. Bani-Hani, "Blockchain smart contracts: Applications, challenges, and future trends," Peer-to-Peer Netw. Appl., vol. 14, no. 5, pp. 2901–2925, Sep. 2021, doi: 10.1007/S12083-021-01127-0/FIGURES/4.

[25] R. Zhang, R. Xue, and L. Liu, "Security and privacy on blockchain," ACM Comput. Surv., vol. 52, no. 3, p. 51, Jul. 2019, doi: 10.1145/3316481.

[26] "AnyLogic for Academia – AnyLogic Simulation Software."

# Code-Mixed Sentiment Analysis using Transformer for Twitter Social Media Data

Laksmita Widya Astuti, Yunita Sari, Suprapto

Department of Computer Science and Electronics, FMIPA UGM Yogyakarta, Indonesia

*Abstract*—The underrepresentation of the Indonesian language in the field of Natural Language Processing (NLP) can be attributed to several key factors, including the absence of annotated datasets, limited language resources, and a lack of standardization in these resources. One notable linguistic phenomenon in Indonesia is code-mixing between Bahasa Indonesia and English, which is influenced by various sociolinguistic factors, including individual speaker characteristics, the linguistic environment, the societal status of languages, and everyday language usage. In an effort to address the challenges posed by code-mixed data, this research project has successfully created a code-mixed dataset for sentiment analysis. This dataset was constructed based on keywords derived from the sociolinguistic phenomenon observed among teenagers in South Jakarta. Utilizing this newly developed dataset, we conducted a series of experiments employing different pre-processing techniques and pre-trained models. The results of these experiments have demonstrated that the IndoBERTweet pre-trained model is highly effective in solving sentiment analysis tasks when applied to Indonesian-English code-mixed data. These experiments yielded an average precision of 76.07%, a recall of 75.52%, an F-1 score of 75.51%, and an accuracy of 76.56%.

*Keywords*—*Sentiment analysis; code-mixed; BERT; bahasa Indonesia*

## I. INTRODUCTION

Indonesia, the fourth most populous country globally, boasts a population exceeding 279 million people, according to estimates provided by the Central Intelligence Agency (CIA) World Factbook. Despite its substantial population, the Indonesian language remains inadequately represented within the realm of Natural Language Processing (NLP). According to Koto et al. [1], this paucity of representation can be attributed to three principal factors: the dearth of annotated datasets, restricted language resources, and a lack of standardization in these resources.

The prevalence of code-mixing, the linguistic phenomenon involving the amalgamation of multiple languages in communication, is influenced by sociolinguistic determinants. As highlighted by Anastassiou and Andreou [12], these determinants encompass individual speaker attributes, the linguistic milieu, the societal status of languages, and everyday language utilization. The coexistence of diverse local languages, regional dialects, and Bahasa Indonesia (the national language) engenders an environment conducive to code-mixing as individuals navigate various linguistic systems. The escalating influence of globalization has engendered a heightened reliance on the English language across the world.

This trend, coupled with the multicultural nature of the community in Jakarta Selatan, further contributes to the phenomenon of code-mixing as an inherent byproduct of linguistic diversity and interactions. The South Jakarta Code-mixed phenomenon presents an avenue for NLP research to confront the intricacies of language and facilitate multilingual communication. Ongoing research endeavors in this field strive to cultivate innovative techniques adept at effectively managing the distinct challenges posed by code-mixed data. Such advancements seek to enhance comprehension and processing capabilities when dealing with multilingual text.

Code-mixing or language mixing in sentiment analysis tasks poses a unique challenge in the field of Natural Language Processing (NLP). Most research on code-mixing is conducted to address sentiment-related issues within monolingual contexts. Given that English is the second most widely used language globally, the likelihood of code-mixing between English and other languages is significant. As a result, the majority of code-mixing research focuses on combinations of English with other languages. However, publicly available code-mixed data between English and Indonesian is scarce, making it challenging to investigate and develop solutions in this area.

Several sentiment analysis studies have been conducted using code-mixed data represented in embeddings. Embeddings are used to represent words in such a way that words that are closer in vector space are expected to have similar meanings. Previous studies include Mishra et al. [2], who used Indian-English and Spanish-English with Glove and TF-IDF as embeddings; Javdan et al. [3], who used Indian-English and Bengali-English with Glove and FastText as embeddings; and Tho et al. [4], who used Indonesian-Javanese with a BERT pretrained model as embedding. Comparative studies conducted by Wang et al. [5] demonstrated that the BERT pretrained model outperforms classic embeddings that are context-independent, such as Glove and FastText. However, these three embeddings are primarily focused on a single language (English), which adversely affects sentiment classification performance.

While many research efforts have aimed to improve sentiment analysis by incorporating code-mixing data from various languages, it's clear that the models used in existing studies are predominantly centered on a single language, specifically, English. This preference for one language in model architecture, along with the neglect of others, can lead to less-than-optimal sentiment analysis results. Moreover, there is a significant scarcity of publicly available code-mixed datasets, especially those annotated with sentiment categories,

particularly for the Indonesian-English language combination. This research gap constrains our understanding of the processes involved in code-mixing between the Indonesian and English languages within the field of Natural Language Processing (NLP), underscoring the necessity to consider both languages, rather than singularly focusing on one. In light of this void, this study makes the following major contributions:

- Constructing a code-mixed Indonesian-English dataset specifically designed for semantic tasks, such as sentiment analysis, and

- Developing five preprocessing scenarios based on pretrained models used in sentiment analysis tasks to address the limitations of embeddings that concentrate solely on one language.

This paper is structured as follows: Section II provides the literature review; Section III encompasses the development of the dataset, including data collection, labeling, the definition of sentiment, preprocessing, and the description of labeling outcomes. Section IV outlines the research methodology, Section V presents the results and discussion, Section VI expounds upon future research directions, and the concluding chapter wraps up the paper in Section VII.

## II. LITERATURE REVIEW

Pretrained models in Natural Language Processing (NLP) have demonstrated their effectiveness in addressing code-mixed challenges by capitalizing on their capacity to learn from extensive and diverse text data. These pretrained models have evolved to become the state-of-the-art models for language comprehension and generation. The foundational data used to train these models is sourced from extensive corpora, including resources such as Wikipedia and book corpuses. Additionally, as outlined by Gupta, Ekbal, and Bhattacharyya [13], existing benchmark datasets across various NLP tasks can be adapted to the code-mixed environment, enabling the assessment of a model's adaptability within a multilingual framework.

Sentiment analysis, a well-established and extensively researched field within social media analysis and NLP, has primarily been conducted in monolingual settings to address sentiment-related concerns. In the realm of code-mixing research, the primary focus has been on combining English with other languages. This emphasis stems from the widespread use of English as the second most spoken language globally, resulting in the prevalence of code-mixing involving English.

In certain sentiment analysis studies, code-mixed data is represented using embeddings, which transform words into vectors, with words of similar meanings residing in close proximity within vector spaces. For example, a study conducted by Mishra, et al. [2] utilized Indian-English and Spanish-English code-mixed data, employing Glove and TF-IDF as embeddings. Similarly, Javdan, et al. [3] employed Indian-English and Bengali-English code-mixed data with Glove and FastText as embeddings, while Tho, et al [4] used Indonesian-Javanese code-mixed data with a Sentence BERT pre-trained model for embedding. In our current study, we employ IndoBERTweet, BERTweet, and Multilingual pretrained models to embed code-mixed data, including Indonesian-English pairs.

Notably, Mishra, et al. [2] conducted code-mixing research involving Indian local languages such as Hindi (HI) and Bengali (BN). The research encompassed various language pairs, including Hindi-English and Bengali-English, employing machine learning and neural networks to address challenges. Feature vectors like GloVe and TF-IDF with 2-6 n-gram characters were employed. However, the study identified several limitations, including the model's difficulty in accurately capturing sentiment polarization from ambiguous data, the limitations of word n-grams in precisely representing sentiment in sentences due to Twitter's character restrictions, and the existence of diverse spelling variations for a single word. Consequently, the use of multilingual embeddings is deemed necessary to accurately classify sentiment and represent words and phrases beyond the lexicon of a single language.

Javdan, et al. [3] conducted sentiment analysis on code-mixed Hindi-English and Spanish-English data using fastText and GloVe embeddings. However, the combination of CNN, fastText, and GloVe resulted in unexpected outcomes with subpar performance. This underperformance was attributed to the exclusion of languages other than English in the embedding process, regardless of the model used. As a result, future studies will prioritize pretraining models in both languages, employing attention mechanisms to determine the significance of each linguistic representation within each phrase.

Furthermore, Tho, et al. [4] evaluated sentiment analysis for Indonesian and Javanese code-mixed data using lexicons and transformers, incorporating an attention mechanism. The transformer model, which leverages the attention mechanism, was employed. Based on the results, the transformer model with BERT encoding demonstrated superior accuracy compared to lexicons. Additionally, a comparative analysis conducted by Wang, et al. [5] revealed that the BERT pretrained model outperforms well-known context-independent embeddings like Glove and FastText. This finding prompted the selection of the BERT pretrained model as the starting point for our current research.

Despite numerous research endeavors that have attempted to enhance sentiment analysis performance using data incorporating code-mixing across different languages, it is evident that the dataset and model architectures employed in existing studies are primarily fixated on a single language, specifically, English. The limitations associated with embedding models trained or biased toward a single language while neglecting others can result in suboptimal sentiment analysis performance. Furthermore, code-mixed datasets, particularly for semantic tasks like sentiment analysis, annotated with sentiment categories, remain notably scarce in the public domain, especially for the Indonesian-English language combination.

This research addresses critical gaps in NLP by focusing on code-mixing challenges involving English and Indonesian, offering a new dataset for sentiment analysis. It also explores preprocessing strategies to enhance sentiment analysis in code-

mixed data. The study contributes to the understanding and management of code-mixed text and aligns with the broader goal of improving multilingual communication and NLP.

## III. Dataset Development

### A. Data Collection Procedure

The data collection methodology entails acquiring data through the submission of requests to Twitter API version 2, amalgamating data in both Indonesian and English languages. A specific authorization, denoted as "Academic research", is imperative for gaining access to Twitter API version 2. The default permission level of Twitter API, referred to as "Essential," is considerably limited and insufficient for conducting crawling operations. Registration is obligatory and necessitates the completion of various inquiries pertaining to the research project. Upon successful registration, an API key is procured. Academic access is indispensable, as it confers numerous advantages that facilitate the research process, including access to real-time public Twitter data and other features that augment accurate and equitable data collection.

A roster of desired keywords is employed as the query or filter for the endpoint, which combs through the entirety of Twitter. The keyword list is amalgamated using the OR operator, signifying a combination of keywords. Additional filters encompass "-is:retweet" to exclude retweeted or shared tweets to avert duplication, "-is:reply" to consider solely original tweets from the tweet author, and "place country:ID" to specify tweets from users located in Indonesia. The selected search terms are derived from sociolinguistic phenomena in Indonesian and English, which are popular among young individuals in the South Jakarta region [9], along with a compilation of pertinent hashtags. The keywords for the endpoint query were gathered from various publications found through Google searches utilizing the term "slang jaksel." The number of keywords obtained from these articles is restricted to 50 and stored in the software as an array. To prepare the training data, the Twitter API v2 and the Python module Tweepy are utilized for the purpose of retrieving code-mixed Indonesian and English data.

The available data spans from August 2020 to September 2022. Along with keywords, the endpoint query also includes date-based queries. The dataset is standardized by dividing it into three sections: testing, validation, and training. The evaluation and dataset distribution adhere to the same F1 value calculation as applied to the IndoLEM dataset in a manner similar to the approach outlined in a study conducted by Koto et al. [1]. The data distribution in this study employs a ratio of 3638 sentences for training, 399 for validation, and 1011 for testing. Considering that the maximum amount of data retrievable per query is 500, queries must be executed in batches.

To mitigate noise within the data, a human data cleaning procedure is executed. This procedure encompasses the removal of duplicate data, the filtration of monolingual data, and the exclusion of offensive or inappropriate terms. After the selection process, the data is annotated with emotions,

specifically categorized as neutral, positive, and negative. These emotions are subsequently translated into numerical values during the training phase, with the assigned values as follows: neutral = 0, negative = 1, and positive = 2.

### B. Data Labeling Procedure

The data labeling procedure involved the collaboration of five annotators with expertise in the fields of data science, English literature, and Indonesian literature. Crowdsourcing was employed to streamline the annotation process, and the services of these annotators were procured through a dedicated freelancing platform tailored specifically for Indonesian professionals (https://projects.co.id). The selection of annotators was based on their knowledge and proficiency in areas directly pertinent to the characteristics of the dataset under investigation.

The tasks assigned to the five annotators were delineated as follows:

*1) Reviewing* tweets provided via the Google AppSheet platform.

*2) Categorizing* the tweets into three distinct sentiment labels: positive, negative, and neutral.

*3) Analyzing* the sentiment groupings based on their pre-existing linguistic expertise.

In order to uphold consistency and precision throughout the annotation process, a majority vote was conducted among the three sets of labeled files. The AppSheet system was seamlessly integrated with Google Sheets, serving as the foundational database from which the annotators read and annotated the tweets. To ensure a more coherent and standardized set of annotated tweets, the final determinations regarding precise sentiment annotations were reached through mutual consensus among the annotators. To enhance comprehension, the consensus on sentiment assessment took into account the context of polarization or sentiment inclination, as well as specific instances. The sentiment categories and their corresponding degrees of polarity are delineated in Table I.

TABLE I. Sentiment Definition based on Polarity Level

| Polarity Level | Definition |
|---|---|
| Positive | A response or outlook that raises the worth of someone or something. |
| Negative | Negative language that will reduce the perceived value of whatever is being viewed. |
| Neutral | Taking no sides |

### C. Dataset Generation Results

According to the labeling distribution determined by the five annotators, the findings revealed that negative labels were more prevalent on Twitter, constituting approximately 35.33% of the data instances, as opposed to neutral labels at approximately 36.19% and positive labels at approximately 28.48%. This distribution was observed in a total of 1,903 out of 5,068 data instances. The distribution results are comprehensively presented in Table II.

TABLE II.    FIVE ANNOTATORS' RESULTS OF LABELING DISTRIBUTION

|  | Positive | Negative | Netral | Total |
|---|---|---|---|---|
| Annotator 1 | 1732 (≈33.98%) | 1213 (≈23.76%) | 2123 (≈42.26%) | |
| Annotator 2 | 1421 (≈27.95%) | 2185 (≈42.84%) | 1462 (≈29.21%) | |
| Annotator 3 | 1039 (≈20.49%) | 2458 (≈48.51%) | 1571 (≈31.00%) | 5068 (100%) |
| Annotator 4 | 1714 (≈33.60%) | 1927 (≈37.59%) | 1427 (≈28.80%) | |
| Annotator 5 | 1784 (≈35.66%) | 1732 (≈33.92%) | 1552 (≈30.42%) | |
| **Average** | 1538 (≈28.48%) | 1903 (≈35.33%) | 1627 (≈36.19%) | |

Description:

- Annotator 1 possesses expertise in the field of Statistics.

- Annotator 2 specializes in Indonesian Literature.

- Annotator 3 has expertise in English Literature.

- Annotator 4 is knowledgeable in the field of English Education.

- Annotator 5 has expertise in English Literature.

### D. Preprocessing

This study will employ various preprocessing methods, encompassing emoji/emoticon conversion, translation, and slang word normalization. Manual data cleaning will be undertaken to eliminate offensive remarks, obscenities, and duplicate entries. Furthermore, automatic preprocessing will be executed by removing unnecessary tokens based on a predefined regular expression. This includes the elimination of acronyms, hashtags, mentions, and URLs. The preprocessing procedure may also encompass converting text to lowercase, addressing coarse language in English, converting emoji/emoticon symbols, normalizing text, performing translation tasks, and eliminating extraneous words. The specific preprocessing techniques employed will be contingent on the selected scenario and the pretrained model in use.

### IV. RESEARCH METHODOLOGY

In a general overview, the research involves five distinct phases for constructing the model. These phases encompass the data collection, data labeling, sentiment polarity determination, training and validation, and the subsequent testing and evaluation processes. The process of dataset development, which includes data collection, labeling, sentiment definition, preprocessing, and the acquisition of labeling results, is elucidated in Section III, specifically under the dataset development section. Fig. 1 depicts the research's overall diagram.
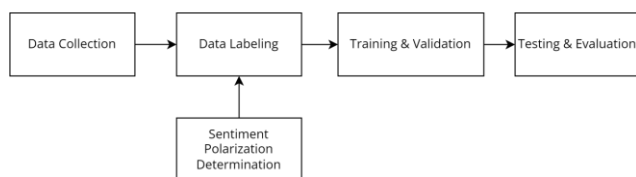


Fig. 1.    The research's stages diagram.

### A. Training, Testing and Validation Process

In the training process, data preparation is carried out, involving data cleaning and preprocessing. Following preprocessing, training is performed using the BERT model. The training process is conducted with three epochs, in accordance with the recommendation by Devlin et al. [7].

Validation occurs concurrently with training to find the lowest loss value among the three epochs. By analyzing the training loss and validation loss values, it can be determined whether the dataset is overfit, underfit, or properly fit to the pretrained model in use. Consequently, the output of the training process is the best model based on the validation results. Given that the primary focus of this research is to compare the use of pretrained models, the selection of epoch, batch, and learning rate values aligns with the fine-tuning procedure outlined by Devlin et al. [7]. The specific values used are adjusted for each pretrained model since they have different optimal hyperparameters. From the chosen best model, a testing process is conducted. The test data is preprocessed using the same procedure as in the training process. The testing process involves comparing the prediction results with the labels in the test data.

### B. Bidirectional Encoder Representations from Transformer (BERT)

Bidirectional Encoder Representations from Transformers (BERT) is a deep learning model designed to generate comprehensive representations of unlabeled text by considering both left and right context at all levels. BERT accomplishes this by incorporating the entire set of words in the surrounding text. Pretrained models based on BERT have proven to be highly effective in representing language due to their extensive training on large corpora and specific domains. The BERT framework consists of two main stages: pretraining and fine-tuning. During pretraining, the model is trained on unlabeled data using various tasks, such as Masked Language Modeling (LM) and Next Sentence Prediction. In the fine-tuning stage, the BERT model is initialized with pretrained parameters and further fine-tuned using labeled data specific to particular tasks.

In this research, the pretrained BERT model is employed to tackle the semantic task of sentiment analysis. The utilization of pretrained models offers significant advantages in natural language processing (NLP) tasks, as it eliminates the need to train new models from scratch. The BERT-based pretrained models utilized in this study include BERTweet, trained on a collection of English tweets [8], IndoBERTweet [6], trained on a collection of Indonesian tweets, and MultilingualBERT [7], trained on a multilingual Wikipedia dataset comprising 104 languages. These pretrained models serve as a foundational point for the sentiment analysis task, leveraging their pre-established knowledge and language representations.

### C. Sentiment Classification

In this research, the classification process leverages the encoding architecture of the transformer. The experiments conducted in this research are based on the implementation of the BERT model provided by Hugging Face. In its entirety, the layers are divided into three parts: the input layer, the attention

layer, and the classification layer. A pretrained model, specifically BERTBase, is utilized as a reference in the training process, with adjustments made for each domain. The parameters of BERTBase used in this study have a larger configuration compared to the transformer parameters defined in previous research Vaswani et al. [19]. BERT incorporates a larger feedforward network, with 768 and 1024 hidden units/embedding sizes, as well as more attention, with 12 and 16 heads, in contrast to the default configuration in the initial Transformer paper (six encoder layers, 512 hidden layers, and eight head attention). The pooler layer in the transformer architecture is employed as input to calculate probabilities and loss values using sigmoid and BCELoss calculations. These computations are conducted in alignment with the specialized BERT implementation for semantic tasks like sentiment analysis. The sigmoid calculation produces logits, which are used to determine whether the sentiment class falls into the categories of neutral, positive, or negative. Meanwhile, the loss value is utilized for validation to select the best model and evaluate whether the trained data exhibits signs of overfitting, underfitting, or a good fit.

### D. Experimental Setup

The dataset employed in this study comprises social media activity data in the form of tweets from Twitter. This dataset encompasses both textual data and emoticons/emojis, as prior research has demonstrated that the inclusion of these types of data enhances the performance of the sentiment analysis pipeline, which is based on BERT [11] and deep learning-based sentiment analysis [10].

TABLE III. FIVE ALTERNATIVE SCENARIOS

| | Step Processes |
|---|---|
| Scenario 1 | 1. Data cleaning<br>2. Preprocessing<br>3. Emoji conversion<br>4. Translation to Bahasa Indonesia<br>5. BERT Training with IndoBERTweet pretrained model<br>6. Validation<br>7. Testing and Evaluation |
| Scenario 2 | 1. Data cleaning<br>2. Preprocessing<br>3. Emoji conversion<br>4. Translation to English<br>5. BERT Training with IndoBERTweet pretrained model<br>6. Validation<br>7. Testing and Evaluation |
| Scenario 3 | 1. Data cleaning<br>2. Normalization to Bahasa Indonesia<br>3. Training with MultilingualBERT pretrained model<br>4. Validation<br>5. Testing and Evaluation |
| Scenario 4 | 1. Training with IndoBERTweet pretrained model<br>2. Validation<br>3. Testing and Evaluation |
| Scenario 5 | 1. Training with MultilingualBERTweet pretrained model<br>2. Validation<br>3. Testing and Evaluation |

A list of 50 keywords is compiled from various online articles, and some of the instances, as illustrated in Table II, are subjected to translation using Google Translate after undergoing preprocessing. The objective is to amass a diverse dataset encompassing data in multiple languages. Additionally,

emoji and emoticons are transformed into plain text using the emoji 1.7.0 library incorporated in the Python package [10]. The sentiment analysis procedure is executed through five distinct scenarios, as outlined in Table III.

### E. Evaluation Process

The evaluation phase is conducted based on the five experimental scenarios that have been established. All five scenarios are tested and evaluated using the same methodology. In the testing phase, labeled test data is utilized to make predictions. The predicted data is then compared to the actual label data, resulting in the creation of a confusion matrix. This confusion matrix is instrumental in determining the count of correct and incorrect predictions based on the respective classes. Metrics calculated include accuracy, precision, recall, and F-measure. Given that this research involves three classes: neutral (0), negative (1), and positive (2), the resulting confusion matrix has a 3x3 dimension, with columns representing predicted sentiment and rows representing the true sentiment. The confusion matrix provides the basis for calculating evaluation metrics, such as precision, recall, F1-score, and overall accuracy for all classes. To compute the values for each metric, one requires the count of true positives, true negatives, false positives, and false negatives.

## V. RESULTS AND DISCUSSION

Leveraging pretrained BERT models has demonstrated notable effectiveness when fine-tuning the sentiment analysis task. These pretrained models provide substantial time and cost savings, as they have already undergone extensive training on large corpora, a process demanding significant computational resources. However, it is crucial to acknowledge that not all pretrained models are equally well-suited for the unique domain of code-mixed data. The comprehensive results of the experiments carried out in this study are presented in Table IV.

TABLE IV. FIVE ALTERNATIVE SCENARIOS

| Scenarios | Precision | Recall | F1-Score | Accuracy |
|---|---|---|---|---|
| Scenario 1<br>IndoBERTweet<br>(*Preprocessing*) | 0.7607 | 0.7552 | 0.7551 | 0.7656 |
| Scenario 2<br>BERTweet<br>(*Preprocessing*) | 0.7314 | 0.7322 | 0.7316 | 0.7389 |
| Scenario 3<br>MultilingualBERT<br>(*Preprocessing*) | 0.6677 | 0.6622 | 0.6631 | 0.6716 |
| Scenario 4<br>IndoBERTweet (Without<br>*preprocessing*) | 0.7396 | 0.7374 | 0.7358 | 0.7478 |
| Scenario 5<br>MultilingualBERT<br>(Without *preprocessing*) | 0.6334 | 0.6345 | 0.6335 | 0.6370 |

Based on insights gained from this research, it is evident that code-mixing between English and other languages can be more optimal and effective when focused on the respective language rather than solely on English. These findings challenge previous studies conducted by Mishra et al. [2], Javdan et al. [3], and Tho et al. [4]. The utilization of the relevant language, in this case, supported by pretraining with a

Bahasa Indonesia-based BERT, adds value to enhancing the performance of a sentiment analysis task.

The experiment findings reveal that Scenario 1, which involves utilizing the pre-trained IndoBERT model along with translation into Indonesian, preprocessing steps such as emoji conversion to plain text, and data cleaning, yields the most favorable results for addressing the Indonesian-English code-mixed problem. In this scenario, an average precision of 76.07%, recall of 75.52%, an f-1 score of 75.51%, and an accuracy of 76.56% were achieved. It's worth noting that the performance, albeit slightly, decreased compared to Scenario 4, which employed the pre-trained IndoBERT model without preprocessing, resulting in an average precision of 73.96%, recall of 73.74%, an f-1 score of 73.58%, and an accuracy of 74.78%. These outcomes underscore the effectiveness of the monolingual Bahasa Indonesia translation and preparation procedure in enhancing performance.

Conversely, the pre-trained Multilingual BERT model exhibited suboptimal performance in Scenarios 3 and 5. However, the inclusion of preprocessing steps led to improved performance outcomes. This phenomenon could be attributed to the fact that the Multilingual BERT training process relies on the Wikipedia corpus, which forms its vocabulary using standard words. Consequently, it is less adept at capturing out-of-vocabulary terms in code-mixed data, including informal words. Additionally, after three epochs of training, the data for the BERTweet pre-trained model showed a good fit, but IndoBERT outperformed it in terms of performance. This may be due to the prevalence of code-mixing and its adherence to Indonesian sentence structure, rendering the translation accuracy of Google Translate less reliable. Based on the aforementioned justifications, here are the outcomes of each of the five scenarios:

- Scenario 1 (pre-trained IndoBERT with preprocessing):

- Average precision: 76.07%, recall: 75.52%, f-1 score: 75.51%, accuracy: 76.56%.

- Scenario 2 (pre-trained Multilingual BERT with preprocessing): Lower performance than Scenario 1.

- Scenario 3 (BERTweet pre-trained model): Exhibited a good fit after three epochs of training but was outperformed by IndoBERT in terms of performance.

- Scenario 4 (pre-trained IndoBERT without preprocessing): Slightly lower performance than Scenario 1.

- Scenario 5 (pre-trained Multilingual BERT without preprocessing): Lower performance than Scenario 1 but improved with preprocessing steps.

The deep learning approach that automatically generates code-mixed text from English into various languages without previous parallel data, as researched by Gupta [13], could be an option for creating a dataset. However, the perspective and role of annotators in determining how sentiment can be defined are crucial in understanding the context of a sentence to be analyzed in the labeling process. This is due to the more complex language composition compared to single language text. Leveraging their expertise, annotators can provide insights into determining sentiment through expressions, emojis/emoticons, context, and emotions. Thus, it is expected that the dataset can contribute to improving performance in various NLP tasks, regardless of the models and scenarios employed.

## VI. FUTURE RESEARCH DIRECTION

Future research is expected to address several key challenges and explore new techniques to enhance the effectiveness and efficiency in handling code-mixed data, particularly the mixing of Indonesian and English in various NLP tasks. The following are some directions for future research:

- Future research efforts may involve enriching the lexicon of non-standard language, both in English and Indonesian, to minimize out-of-vocabulary words. Additionally, exploring the conversion of emojis and emoticons within multilingual BERT scenarios (given its training on standard corpora like Wikipedia) to make it applicable to Twitter sentences.

- As preprocessing has a substantial impact on this study, further investigation is needed to develop better and more optimal preprocessing methods for effectively handling code-mixed data.

- Research in the future could consider creating pretrained models on code-mixed data corpora without retaining the existing scenarios. This approach, while taking into account each language to avoid ambiguity, would allow sentiment analysis processes to run without the need for tuning existing monolingual pretrained models.

## VII. CONCLUSION

This research project has successfully curated a code-mixed dataset by amalgamating Indonesian and English languages, utilizing 50 keywords derived from a sociolinguistic phenomenon observed among teenagers in South Jakarta. The presence of code-mixing, which results from the combination of two distinct languages, underscores the significance of involving language experts in determining sentiment polarity. This engagement is essential for enhancing the accuracy of sentiment analysis, given the heightened linguistic complexity compared to single-language text. By capitalizing on their expertise, annotators can offer valuable insights for ascertaining sentiment based on expressions, emojis/emoticons, context, and emotional cues. Consequently, the dataset is anticipated to make a meaningful contribution to enhancing performance across a range of NLP tasks, irrespective of the specific models and scenarios used. The dataset was meticulously designed to tackle the semantic task of sentiment analysis, incorporating three distinct label categories: positive, negative, and neutral. The annotation of the dataset was carried out by a panel of five annotators, each possessing expertise language and data science. The dataset has been made publicly available on the Github repository and can be accessed via the following link: https://github.com/laksmitawidya/indonglish-dataset.

Despite being initially trained on a monolingual corpus, the BERT pretrained model exhibits impressive performance when handling code-mixed data in sentiment analysis tasks. Furthermore, each pretrained model demands only a brief training period of approximately four hours on a CPU. This underscores the significant role of pretrained models in expediting the training process in specialized domains, such as sentiment analysis of Twitter data containing both Indonesian and English codes, while keeping computational resource requirements minimal.

Leveraging pretrained BERT models has proven effective in fine-tuning sentiment analysis tasks, resulting in substantial time and cost savings due to their extensive training on large corpora. It's worth emphasizing that not all pretrained models are equally suitable for code-mixed data, and the application of scenario-based preprocessing significantly impacts performance outcomes. The findings of this research highlight the effectiveness of concentrating on the respective language in code-mixing between English and other languages, as opposed to a sole emphasis on English. These insights challenge the conclusions drawn in prior studies. Notably, incorporating the relevant language, particularly when supported by pretraining with a Bahasa Indonesia-based BERT, emerges as a valuable approach to significantly improve the performance of sentiment analysis tasks. Specifically, Scenario 1, which combines the pre-trained IndoBERT model with preprocessing, emoji conversion, and data cleaning, delivers highly favorable results for Indonesian-English code-mixed sentiment analysis, achieving notable average precision, recall, f1-score, and accuracy values of 76.07%, 75.52%, 75.51%, and 76.56%, respectively. This emphasizes that data cleansing, translation to a unified language, and normalization during the preparation stage are adequate for enhancing performance. On the other hand, the Multilingual BERT model initially exhibits suboptimal performance in specific scenarios but shows improvement with the introduction of preprocessing steps, revealing its limitations in capturing out-of-vocabulary terms in code-mixed data. Looking ahead, future research should prioritize enriching non-standard language lexicons, optimizing preprocessing techniques, and exploring pretrained models for code-mixed data without relying on specific scenarios. These endeavors aim to enhance sentiment analysis performance in multilingual contexts, ultimately contributing to improved accuracy and efficiency.

## ACKNOWLEDGMENT

## REFERENCES

[1] Koto, F., Rahimi, A., Lau, J. H., and Baldwin, T., "IndoLEM and IndoBERT: A Benchmark Dataset and Pre-trained Language Model for Indonesian NLP", Proceedings of the 28th International Conference on Computational Linguistics, pp. 757–770, 2020.

[2] Mishra, P., Danda, P., and Dhakras, P, "Code-Mixed Sentiment Analysis Using Machine Learning and Neural Network Approaches", arXiv:1808.03299. 2018 [Online]. Available: https://arxiv.org/abs/1808.03299

[3] Javdan, S., ataei, T. S., and Minaei-Bidgoli, B, "IUST at SemEval-2020 Task 9: Sentiment Analysis for Code-Mixed Social Media Text using Deep Neural Networks and Linear Baselines", Proceedings of the Fourteenth Workshop on Semantic Evaluation, pp. 1270–1275, Dec. 2020 [Online]. Available: https://aclanthology.org/2020.semeval-1.170

[4] Tho, C., Heryadi, Y., Kartowisastro, I. H., and Budiharto, W., "A Comparison of Lexicon-based and Transformer based Sentiment Analysis on Code-mixed of Low-Resource Languages", International Conference on Computer Science and Artificial Intelligence (ICCSAI), pp. 81-85, 2021 [Online]. Available: https://ieeexplore.ieee.org/document/9609781.

[5] Wang, C., Nulty, P., and Lillis, D, "A Comparative Study on Word Embeddings in Deep Learning for Text Classification., Natural Language Processing and Information Retrieval", pp. 18-20, Oct. 2020.

[6] Koto, F., Lau, J. H., and Baldwin, T, "IndoBERTweet: A Pretrained Language Model for Indonesian Twitter with Effective Domain-Specific Vocabulary Initialization", Proceedings of the 2021 Conference on Empirical Methods in Natural Language Processing, pp. 10660–10668, 2021 [Online]. Available: https://aclanthology.org/2021.emnlp-main.833.

[7] Devlin, J., Chang, M.-W., Lee, K., and Toutanova, K, "BERT: Pre-training of Deep Bidirectional Transformers for Language Understanding, Google AI Language", 2019 [Online]. Available: https://aclanthology.org/N19-1423.pdf

[8] Nguyen, D. Q., Vu, T., & Nguyen, A. T. (2020). "BERTweet: A pre-trained language model for English Tweets". Proceedings of the 2020 EMNLP (Systems Demonstrations), 9–14.

[9] Wijaya, A. D., and Bram, B., "A Sociolinguistic Analysis of Indoglish Phenomenon in South Jakarta", Professional Journal of English Education, pp. 672-684, 2021.

[10] Ullah, M. A., Marium, S. M., Begum, S. A., and Dipa, N. S., "An algorithm and method for sentiment analysis using the text and emoticon", ICT Express 6, pp. 357–360, 2020.

[11] Pota, M., Ventura, M., Catelli, R., and Esposito, M., "An Effective BERT-Based Pipeline for Twitter Sentiment Analysis: A Case Study in Italian", Sensors, pp. 1-21, 2021.

[12] Anastassiou, F., Andreou, G., "Factors Associated with the Code Mixing and Code Switching of Multilingual Children: An Overview", International Journal of Linguistics, Literature and Culture (LLC) , 13-26. 2017.

[13] Gupta, D., Ekbal, A., & Bhattacharyya, P, "A Semi-supervised Approach to Generate the Code-Mixed Text using Pre-trained Encoder and Transfer Learning", Association for Computational Linguistics, 2267–2280, 2017.

# Research on the Application of Random Forest-based Feature Selection Algorithm in Data Mining Experiments

Huan Wang*

College of Big Data and Intelligence Engineering, Southwest Forestry University, Kunming, Yunnan, 650224, China

*Abstract*—Handling high-dimensional big data presents substantial challenges for Machine Learning (ML) algorithms, mainly due to the curse of dimensionality that leads to computational inefficiencies and increased risk of overfitting. Various dimensionality reduction and Feature Selection (FS) techniques have been developed to alleviate these challenges. Random Forest (RF), a widely-used Ensemble Learning Method (ELM), is recognized for its high accuracy and robustness, including its lesser-known capability for effective FS. While specialized RF models are designed for FS, they often struggle with computational efficiency on large datasets. Addressing these challenges, this study proposes a novel Feature Selection Model (FSM) integrated with data reduction techniques, termed Dynamic Correlated Regularized Random Forest (DCRRF). The architecture operates in four phases: Preprocessing, Feature Reduction (FR) using Best-First Search with Rough Set Theory (BFS-RST), FS through DCRRF, and feature efficacy assessment using a Support Vector Machine (SVM) classifier. Benchmarked against four gene expression datasets, the proposed model outperforms existing RF-based methods in computational efficiency and classification accuracy. This study introduces a robust and efficient approach to feature selection in high-dimensional big-data scenarios.

*Keywords—Random forest; SVM; machine learning; big data; feature selection; best-first search; rough set theory*

## I. INTRODUCTION

High-dimensional big data poses significant challenges for Machine Learning (ML) algorithms due to the "curse of dimensionality," a phenomenon where the computational complexity and resource requirements increase exponentially as the number of dimensions (features) grows [1]. Traditional algorithms can struggle to make accurate predictions as they become lost in the vastness of the feature space, leading to issues such as overfitting, where the model captures noise instead of the underlying data structure. To mitigate these problems, various dimensionality reduction techniques like Principal Component Analysis (PCA), t-distributed Stochastic Neighbor Embedding (t-SNE), and autoencoders have been developed to compress the feature space while retaining as much of the meaningful information as possible [2]. Additionally, feature selection methods like the Least Absolute Shrinkage and Selection Operator (LASSO), Mutual Information (MI), and Chi-Square Test (CST) are used to identify the most informative features. More sophisticated ML models, such as Deep Learning (DL) models, are also designed to automatically capture hierarchical representations of the data, thereby mitigating some of the challenges posed by high dimensionality.

The Random Forest (RF) technique is a collective learning approach that integrates numerous decision trees to build a more robust and precise forecasting model. Functionally, each tree in the ensemble is built from a bootstrapped sample of the data, and during the tree-building process, a random subset of features is chosen at each node split [3]. This randomization not only decorates the trees but also makes the ensemble less prone to overfitting, enabling it to perform well on unseen data. As a predictor, RF is renowned for its exceptional accuracy, capability to process vast datasets with extensive dimensionality, and capability to handle missing values. One of the lesser-known but advantageous features of an RF model is its innate capability for Feature Selection (FS) [4]. During training, it computes a score for each feature that indicates its importance in making predictions. This feature importance score is often derived from the average reduction in impurity that each feature brings across all trees in the forest. By ranking features based on this score, RF provides a practical and intuitive way for FS, helping to improve the performance of not only itself but also other ML models that may be sensitive to irrelevant or redundant features [5].

Many RF models are specialized for FS, each offering unique advantages and disadvantages. Variants like Boruta [6] focus on systematically identifying important attributes by comparing them to randomly shuffled versions of themselves, while Conditional Inference Forest (CIF) [7] aims for unbiased FS through statistical hypothesis tests. Regularized RF [8] applies a regularization term to prioritize a sparse set of features, and Extremely Randomized Trees (RT) [9] adds an extra layer of randomness for potentially more robust selections. However, a common drawback in most of this RF-based Feature Selection Model (FSM) is their lack of focus on handling large datasets. These methods often strive for computational efficiency, facing challenges related to memory space and computing time. To mitigate these issues, high-performance computing environments and parallel architectures are often necessary for effective FS on big datasets. Failing to use such computational resources can significantly ramp up hardware and software costs. For example, scalable software frameworks like Hadoop MapReduce are often required for the learning and analysis stages to manage large datasets efficiently. Therefore, while RF-based methods offer numerous avenues for FS, their

applicability to big data scenarios often necessitates additional computational resources to overcome inherent limitations.

Considering the challenges associated with computational time complexity and classification accuracy in high-dimensional datasets, a novel FSM integrated with data reduction techniques is proposed. The architecture operates in four distinct phases. Initially, high-dimensional data undergo preprocessing to standardize and clean the dataset. Subsequently, the preprocessed data are processed through a Best-first Search with Rough Set Theory (BFS-RST) Feature Reduction Model (FRM) in the second phase. This specialized model aims to reduce the feature size effectively. In the third phase, a novel proposed variant of RF termed Dynamic Correlated Regularized Random Forest (DCRRF) is employed. This DCRRF model incorporates correlated FSM to identify an optimal set of features from the already-reduced set. The final phase involves a rigorous assessment of the quality and efficacy of the FS using a Support Vector Machine (SVM) classifier. Performance benchmarks indicate that this proposed model outperforms existing RF-based FSM when tested on four gene expression datasets. The architecture aims to mitigate computational inefficiency and enhance classification accuracy, offering a more robust approach to FS in complex data scenarios.

The paper is organized as follows: Section II presents the literature review, Section III presents the methodologies used in the work, Section IV presents the proposed model, Section V analyses the work using different experiments, and Section VI concludes the work.

## II. LITERATURE REVIEW

This section delves into various works that have employed RF-based models for FS, offering insights into their efficacy and limitations.

The research in [10-12] presents a two-step RF-based FSM. The first step selects features based on variable importance scores and then employs the search process in the second step to finalize a feature subset. The approach was tested on the KDD'99 intrusion detection dataset, derived from the DARPA 98 dataset. Notably, the KDD'99 dataset was modified to remove redundant records, resulting in a refined dataset called RRE-KDD for training and testing. Experimental results indicated that this approach reduced the feature set and computational time and enhanced classification accuracy. The study in [13-15] explores the use of the RF classifier for FS in prostate cancer detection. Utilizing an ensemble of Decision Trees (DT) for classification, the study notes that the accuracy improves with adding more trees. The classifier is adept at handling incomplete data attributes and is scalable for large datasets. Emphasizing the pivotal role of FS, the research finds that their method boosts detection accuracy by roughly 87%, underscoring the importance of effective FS in enhancing prostate cancer detection. The research in [16-18] study introduces a recursive FSM using RF to enhance protein structural class prediction. The method underwent evaluation through four experiments and was compared to existing prediction techniques. Findings suggest that this feature selection approach significantly bolsters the efficiency of predicting protein structural classes. Remarkably, the method uses fewer than 5% of the features yet boosts prediction accuracy by 4.6-13.3%. Further analysis revealed that features related to predicted secondary structures yielded the best performance, providing insights that could inform the development of even more effective prediction methods for protein structural classes.

The study in [19-23] explores how the number of trees and class separability influence the consistency of variable importance rankings in RF algorithms. The research concludes that achieving stable importance values is possible either by incorporating a large number of trees in a single execution of the model or by taking the average values from multiple runs with fewer trees. While the second approach is more economical regarding computational cost, both methods produce comparable rankings for the variables. The research additionally points out that the ideal number of model iterations fluctuates depending on class separability and offers recommendations for ascertaining the appropriate number of runs or trees to achieve stable rankings of variable importance. In study [24-28], introduce an explainable Artificial Intelligence (AI) model for blood test sample-based COVID diagnosis. Despite the advancements in AI-based diagnostic models, few effectively integrate human-centered and machine-centered approaches. This research employs human-computer interaction design principles to address this gap. Employing graph analysis for the visualization and optimization of features, the model integrates an interpretable decision forest classifier to categorize COVID-19 cases using existing blood test information. This enables clinicians to leverage DT structures and feature visualizations for better model interpretability. They proved that their model had not just better diagnostic accuracy but also reduced computation time.

The research in [29-34] examines the efficacy of ML algorithms like RF and its variations in selecting Single Nucleotide Polymorphisms (SNPs) for fine-scale genetic population assignment in wildlife conservation. The study, which uses unpublished data for Atlantic salmon and published data for Alaskan Chinook Salmon (ACS), found that ML methods outperformed traditional Fixation Index (FST) rankings in identifying informative genetic markers. Specifically, RF-based methods led to an accuracy improvement of up to 7.8% and 11.2% for ACS, respectively. The findings underscore the potential of ML algorithms in enhancing genetic marker selection for conservation efforts. The research in [35-40] addresses the challenges in intrusion detection systems, such as the scarcity of labeled datasets, computational overhead, and suboptimal accuracy. The research introduces an Auto-Encoder Intrusion Detection System (AE-IDS) that leverages the RF algorithm for improved performance. The approach focuses on creating a robust training set through FS and grouping in [41-45]. Post-training, the model employs an auto-encoder for prediction, significantly reducing detection time and enhancing accuracy. Experimental findings suggest that AE-IDS outperform conventional ML-based IDS, offering more accessible training, better adaptability, and higher detection accuracy in [46-50]. The research in [51-55] employs an RF algorithm for county-scale cotton mapping, using spectral, vegetation, and

texture features. The study found that texture features, particularly the Gray Level Co-occurrence Matrix (GLCM), significantly improve classification accuracy. Compared to other classifiers like SVM and ANN, RF exhibited better stability and higher accuracy. The method that combined multiple features achieved an average accuracy of 93.36%, showing the effectiveness of using RF and multiple features for precise cotton mapping [56-58].

## III. PROPOSED METHODOLOGIES

### A. Random Forest

RF is an Ensemble Learning (EL) algorithm that builds a forest of DT, usually trained with the "bagging" method. The general idea of the Ensemble Learning Method (ELM) is to combine weak learners to create a robust model. In RF, each DT, $T_m$ is trained on a different bootstrap sample $D_m$ Drawn from the original dataset. The algorithm performs this operation $M$ times based on the parameter $n_{est}$, effectively creating $M$ different trees. A unique aspect of RF is that it considers only a subset of features when making each split, a number specified by the parameter $max_f$. This random subset of features introduces diversity among the trees, leading to a more robust model.

For regression problems, the output of a RF model is the mean prediction of all the trees, mathematically expressed as Eq. (1).

$$\hat{Y}(X) = \frac{1}{M}\sum_{m=1}^{M} T_m(X) \quad (1)$$

In classification tasks, the model employs a Majority Voting Scheme (MVS), choosing the mode of the classes predicted by individual trees, given as Eq. (2).

$$\hat{Y}(X) = \text{mode}(T_1(X), T_2(X), \dots, T_M(X)). \quad (2)$$

This EML provides a way to reduce the variance that might be present in a single DT, improving generalization to unseen data. One of the essential aspects of RF is the criteria used for node splitting, often specified by the Gini Impurity (GI) as shown in Eq. (3).

$$G(S) = 1 - \sum_{i=1}^{k} p_i^2, \quad (3)$$

where $p_i$ is the proportion of samples of class $i$ at a node, GI quantifies the "messiness" of the data. The algorithm aims to minimize the weighted sum of the GI of child nodes when making each split. This weighted sum can be calculated as in Eq. (4).

$$\Delta G = \sum_{j=1}^{2} \frac{|S_j|}{|S|} G(S_j). \quad (4)$$

In addition to GI, entropy is another criterion which is sometimes used for splitting nodes, defined as $H(S) = -\sum_{i=1}^{k} p_i \log_2 p_i$. The algorithm then selects the split that maximizes the information gain, calculated as in Eq. (5).

$$IG(S, f) = H(S) - \sum_{j=1}^{2} \frac{|S_j|}{|S|} H(S_j). \quad (5)$$

One lesser-known but critical aspect of RF is the Out-of-Bag (OOB) error. This internal error estimate eliminates the need for a separate validation set. Each tree in the forest leaves

out some samples during its bootstrap training, called OOB samples. The OOB error for each tree $T_m$ is calculated using its corresponding $OOB_m$ samples as in Eq. (6).

$$OOB_{error\,T_m} = \frac{1}{|OOB_m|} \sum_{(x_i, y_i) \in OOB_m} L(y_i, T_m(x_i)) \quad (6)$$

The overall OOB error for the RF is the average of these individual tree OOB errors as shown in Eq. (7).

$$\text{Overall } OOB_{error} = \frac{1}{M}\sum_{m=1}^{M} OOB_{error\,T_m} \quad (7)$$

where, $L(y, \hat{y})$ is a loss function measuring the difference between the true label $y$ and the predicted label $\hat{y}$.

*Algorithm 1 for RF Algorithm*

*Initialize Parameters:*

*(i) tree count in the forest (M): "$n_{est}$"*

*(ii) features needed for each split: "$max_f$"*

*(iii) each tree's maximum depth: "$max_d$"*

*(iv) the sample count needed to split a node: "$minsam_{split}$"*

*(v) The sample count needed to be a leaf node: "$minsam_{leaf}$".*

*For $m = 1$ to:*

- *Bootstrap Sampling*
- *Draw a bootstrap sample $D_m$ of size N from the training dataset.*
- *Identify Out-of-Bag samples $OOB_m = D - D_m$*
- *Build Tree $T_m$*
- *Initialize the root node with $D_m$*

*For Each node:*

- *Check Terminal Conditions*

*If depth equals $max_d$ or $|D_m| < minsam_{split}$ or $|D_m| < minsam_{leaf}$, make the node a leaf and stop.*

*Feature Selection*

- *Randomly select $max_f$ Features without replacement.*

*Find Best Split*

*For Each*

- *FS compute the best split based on either GI or Entropy.*
- *The best split minimizes the weighted GI or maximizes Information Gain.*

*Split the Node*

- *Divide $D_m$ into two subsets $D_{m,left}$ and $D_{m,right}$ based on the best split.*

*Recursive Split*

- *Repeat steps 1.2.1 to 1.2.4 for the child nodes $D_{m,left}$ and $D_{m,right}$.*

*Calculate OOB Error for $T_m$*

- $OOB_{error\ T_m} = \frac{1}{|OOB_m|}\sum_{(x_i,y_i)\in OOB_m} L(y_i, T_m(x_i))$

*Calculate Overall OOB Error*

- *Overall $OOB_{error} = \frac{1}{M}\sum_{m=1}^{M} OOB_{error\ T_m}$*

*End If*

*End*

*1) Variable importance scores from RF*: RF is not only known for its robust predictive power but also for its built-in FS capabilities. One of the metrics that the algorithm provides for understanding the dataset is the variable importance score for each feature. Understanding variable importance is crucial for improving and interpreting the model's decisions. The variable importance score in an RF algorithm is computed based on two principal factors:

*a) Mean Decrease in Impurity (MDI)*: This method calculates the average reduction in impurity-Gini impurity or entropy, for example, for each feature brought about when used for node splitting. Mathematically, the Mean Decrease in Impurity for feature f is computed as shown in Eq. (8).

$$MDI(f) = \sum_{\text{all nodes using } f} (\text{Impurity of Parent Node - Weighted Impurity of Child Nodes})$$
(8)

*b) Mean Decrease in Accuracy (MDA):* Another method, which usually involves using the Out-of-Bag (OOB) error, calculates the decrease in model accuracy when a particular feature is permuted. The idea is to assess how much worse the model performs without each feature. The formula for MDA can be generalized as Eq. (9).

$$MDA(f) = \frac{1}{M}\sum_{m=1}^{M}\left(OOB\_Error_{\text{with } f} - OOB\_Error_{\text{without } f}\right)$$
(9)

*Calculation Steps:*

*Step 1.* *Run the RF Algorithm:* First, generate the RF model using all variables and calculate the OOB error rate.

*Step 2.* *Permute Each Variable:* For Each feature $f$ in the dataset, randomly permute the values of $f$ in the OOB samples and record the new OOB error.

*Step 3.* *Compute Importance:* For Each feature $f$, compute the Mean Decrease in Accuracy or Mean Decrease in Impurity, depending on which method you're using.

*Step 4.* *Normalize Scores:* The raw importance scores can be normalized to sum to one, making them easier to interpret and compare.

*2) Regularized random forest (RRF):* RRF is an advanced extension of the traditional RF algorithm. While RF is already effective in ensemble learning, RRF takes a step further by incorporating regularization techniques aimed at reducing overfitting and improving feature selection. In standard RF models, each DT $T_m$ is trained independently on a bootstrap sample $D_m$, with no explicit mechanism for feature regularization. RRF, however, adds a regularization term to the ELM, effectively penalizing the complexity of individual trees.

The objective function for each tree in RRF can be mathematically represented as in Eq. (10).

$$Objective(T_m) = Impurity(T_m) + \lambda Complexity(T_m)$$
(10)

Here, Impurity $(T_m)$ refers to the impurity measure, which can be either GI or entropy. Complexity $(T_m)$ is a function quantifying the complexity of the tree, such as the depth or the number of leaves. $\lambda$ is the regularization parameter controlling the trade-off between impurity and complexity. This parameter is usually determined through cross-validation. In the RRF model, the standard information gain is replaced by a regularized form, $Gain_R(X_i, v)$, which integrates the regularization term:

$$Gain_R(X_i, v) = \begin{cases} \lambda \times Gain(X_i, v) & \text{if } i \notin F \\ Gain(X_i, v) & \text{if } i \in F \end{cases}$$
(11)

Here, $F$ is the set of feature indices already used for splitting in previous nodes. The term $\lambda$ serves as the penalty coefficient. Regularization in RRF can be applied at different stages:

- During Feature Selection: The regularization term is incorporated into the evaluation metric used for selecting the features for node splitting.

- During Tree Pruning: After constructing the trees, they can be pruned to minimize the regularized objective function.

By introducing the regularization term, RRF balances model complexity and fit quality, ensuring a more interpretable and robust ensemble model. This is particularly useful in cases where the dataset contains many irrelevant features or when overfitting is a concern. Therefore, RRF benefits from the inherent advantages of Random Forests while simultaneously mitigating some of their limitations.

*B. Best-First Search (BFS)*

BFS is a tree-based search algorithm that aims to find the most optimal solution by navigating through the state space of possible solutions. In the context of feature selection, each node $N$ in the search tree represents a subset of features $S$, and the root node usually represents an empty set or the complete feature set. The primary driving force of the algorithm is an evaluation function $f(N)$, which measures the 'quality' or 'promising nature' of node $N$. Mathematically, the evaluation function $f(N)$ can be expressed as in Eq. (12).

$$f(N) = g(N) + h(N)$$
(12)

where, $g(N)$ is the cost to reach the current node from the root (often equal to the number of features in $S$ when feature reduction is the goal), and $h(N)$ is the heuristic estimate of the cost to reach an optimal solution from $N$. The algorithm maintains a priority queue $Q$, initialized with the root node. The nodes are sorted in $Q$ based on their evaluation scores. The algorithm iteratively performs the following steps until a stopping criterion is met:

*Algorithm 2 for BFS for FS*
*Input:*

- *S : Complete set of features*

- *$f(N)$: Evaluation function for a node N*

- *Stopping Criteria: C*

*Output:*

- *Optimal subset of features $S_{optimal}$*
  *Initialize:*

- *Create an empty priority queue Q*

- *Create a root node $N_{root}$ with no features or all features, add $N_{root}$ to Q*

*Steps:*

*While Q is not empty and stopping criteria C are not met:*

- *Pop the node N with the lowest $f(N)$ from Q If N satisfies C :*

*Return $S_{optimal}$ as the feature subset in N*

*Exit*

*Else*

- *Generate child nodes of N by adding or removing features from S Evaluate $f(N)$ For Each Child Node*
- *Insert the child nodes into Q*
- *Re-sort Q based on $f(N)$*

The mathematical representation of the priority queue after *'k'* iterations can be represented as in Eq. (13).

$$Q_k = \{N_1, N_2, \dots, N_m\} \text{ s.t. } f(N_1) \leq f(N_2) \leq \cdots \leq f(N_m) \tag{13}$$

By focusing on the most promising subsets of features, BFS achieves a balance between exhaustive search and greedy algorithms. However, it can be computationally intensive, especially when the feature space is ample, as the time complexity can go up to $O(b^d)$, where $b$ is the branching factor, and $d$ is the depth of the solution.

*C. Rough Set Theory (RST)*

FR helps reduce the computational cost, simplifying models and sometimes even improving the performance by eliminating irrelevant or redundant features. RST developed that can be employed for feature reduction. RST provides a formal mathematical framework to deal with vagueness and uncertainty in data. In the context of Feature Reduction (FR), it helps identify the minimal set of features indispensable for preserving the discernibility between objects. In simpler terms, it helps find the most miniature set of features necessary and sufficient for classification tasks.

Let $U$ represent the universe of objects or instances in the dataset, and let $A$ denote the set of attributes or features. A decision table $T = (U, A)$ may be formed, in which $U$ comprises the rows, and $A$ makes up the columns. Additionally, $D$ a subset of $A$, can be introduced as the decision attribute(s) of interest. Using this foundation, the following aspects of RST are discussed:

*a) Indiscernibility Relation:* The fundamental concept in RST is the indiscernibility relation. For a given subset of attributes, $B \subseteq A$ an indiscernibility relation $IND(B)$ is defined as follows in Eq. (14).

$$IND(B) = \{(x,y) \in U \times U \mid \forall a \in B, a(x) = a(y)\} \tag{14}$$

Here, $a(x)$ is the value of attribute $a$ for object $x$. The indiscernibility relation $IND(B)$ groups objects that cannot be distinguished by attributes in $B$

*b) Lower and Upper Approximations:* Given a target set $X \subseteq U$, the lower and upper approximations are defined as in Eq. (15) and Eq. (16).

$$\text{Lower Approximation: } \underline{B_X} = \{x \in U \mid [x]_B \subseteq X\} \tag{15}$$

$$\text{Upper Approximation: } \overline{B_X} = \{x \in U \mid [x]_B \cap X \neq \emptyset\} \tag{16}$$

Here, $[x]_B$ represents the equivalence class of $x$ concerning $B$.

*c) Core and Reduct:* The core attributes are indispensable for maintaining the exact lower approximation for every subset of $U$ as the entire set $A$. Mathematically, Eq. (17).

$$\text{Core}(A, D) = \left\{ a \in A \mid \underline{A_D} \neq \underline{(A - \{a\})_D} \right\} \tag{17}$$

A reduct is a minimal subset $B$ of $A$ such that $\underline{B_D} = \underline{A_D}$. In other words, $B$ and $A$ give the same lower approximations for each decision class.

*D. Feature Reduction using RST*

The overarching goal is to identify all possible reducts and then choose the one with the least number of attributes while preserving the classification power of the original dataset. However, finding all reducts can be computationally taxing. For this reason, heuristic approaches are frequently used to approximate a minimal reduct effectively.

*1) Initialize with core attributes*: Start by calculating the core attributes, denoted as Core $(A, D)$, which are essential for classification. Initialize the reduct set, Reduct, with these core attributes.

*2) Iterative refinement*: Continue refining the reduct set until it provides the same classification power as the complete

attribute set $A$. Specifically, iterating while reducing $_D$ is not equal to $\underline{A_D}$.

- Evaluate Significance: For each remaining attribute $a$ in $A$ - Reduct, evaluate its significance in distinguishing between different classes.

- Select Most Significant Attribute: Add the attribute with the highest significance score to the Reduct set.

By the end of this iterative process, Reduct will contain a minimal set of attributes that retains the original dataset's ability to distinguish between different classes.

*E. Correlation-based Feature Selection (CFS)*

CFS is an FSM designed to improve model performance by FS that are highly correlated with the target variable and minimally correlated with each other. The process typically begins with data preprocessing to standardize or normalize the features then calculating a correlation matrix. Based on this matrix, an initial subset of FS either through predefined correlation thresholds or optimization algorithms. The criterion $Cr$, often used to maximize the quality of the feature subset, is Eq. (18).

$$Cr = \frac{k \cdot \tau_{cf}^-}{\sqrt{k + k \cdot (k-1) \cdot r_{ff}^-}}, \qquad (18)$$

where, $k$ is the number of features, $r_{cf}^-$ is the average correlation between features and the class label, and $r_{ff}^-$ is the average inter-feature correlation. This subset is then further evaluated using methods like cross-validation.

It is important to note that the CFS employs a heuristic search strategy within its multivariate FS algorithm to pinpoint optimal attributes in a given dataset. The criteria for selection are anchored in the correlation strength and statistical significance between a feature and its associated category. This unique capability has solidified CFS's role as a go-to method for Feature Extraction (FE), especially in large-scale data environments. Moreover, CFS has yielded numerous impactful findings that contribute to elevating the efficacy of Decision-Making System (DMS).

The advantages of CFS are manifold. It tends to produce more superficial and interpretable models by decreasing the feature size, thus mitigating the risk of overfitting. However,

the method is not without limitations. For example, Pearson's correlation, which is commonly used, assumes a linear relationship between variables and does not capture feature interactions. Despite this, CFS remains a powerful FSM, aiming to optimize the model's performance and generalization capabilities. When integrated with techniques like Regularized Random Forest (RRF), CFS can further enhance the FSM, leveraging the regularization capabilities of RRF to produce an even more robust and interpretable model.

## IV. PROPOSED FSM

In the architecture of the proposed FSM, as shown in Fig. 1, four key steps seamlessly integrate to provide a holistic solution. Initially, the dataset undergoes a preprocessing phase, which includes tasks like data normalization, formatting, and randomization, preparing the data for rigorous analysis. Following preprocessing, the first significant phase employs the innovative BFS-RST Adaptive Algorithm to reduce the feature set effectively. Utilizing this algorithm allow for a focus on a subset of features that are most relevant to the task, thereby enhancing the model's efficiency. This reduced feature set serves as the input to the second crucial phase, which features the Dynamic Correlated Regularized Random Forest (DCRRF) application. DCRRF refines FS dynamically, optimizing performance and interpretability through a combination of Correlation-based Feature Selection (CFS) and Regularized Random Forest (RRF) methodologies. After the optimal feature set has been identified, the final step involves a data analysis phase where the effectiveness of the selected features is rigorously tested using a Support Vector Machine (SVM) classifier. This multi-layered approach enhances the feature selection process and lends itself to detailed performance evaluation, making it a comprehensive solution for complex data analysis scenarios.

*A. Data Preprocessing*

The first step in the proposed FSM is Data Preprocessing. This phase is crucial because it converts the raw dataset into a more manageable, clean form, making it easier to analyze and feed into subsequent FR and FS stages. A properly preprocessed dataset not only streamlines the FSM but also contributes to the robustness and interpretability of the resulting model. The following methods are used in the preprocessing pipeline of the proposed architecture:
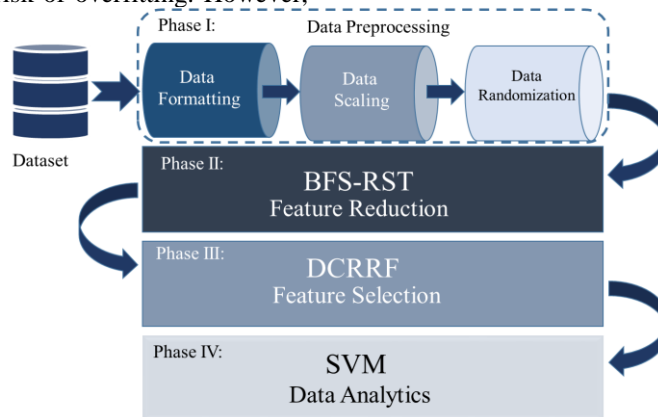


Fig. 1. Proposed FSM.

- Data Formatting: Including Data Formatting as the initial step in the preprocessing pipeline is fundamental for making the dataset readable and interpretable by the following algorithms. Addressing issues like inconsistent data types and missing values eliminates the potential for errors or biases that could significantly affect the performance of the BFS-RST Adaptive Algorithm and DCRRF. Proper formatting is a stable foundation for the stages that follow in the feature selection model.

- Data Scaling: Data Scaling finds its place in the preprocessing phase due to its significant impact on any ML algorithm's performance. The scales of numerical features can vary widely, and a feature with a more extensive range could overshadow those with smaller ranges, leading to suboptimal FS or model training. Scaling standardizes this, ensuring that each feature is given equal importance, thereby enhancing the overall reliability and effectiveness of the BFS-RST and DCRRF algorithms.

- Data Randomization: Data Randomization is incorporated to mitigate any sequence-based biases in the dataset. Data points can come in sequences that may reflect various forms of underlying structure or bias, such as time-based or class-based ordering. Shuffling the order of data points enables the FSM, which employs both the BFS-RST and DCRRF algorithms, to learn more objectively, uninfluenced by the sequence in which the data points initially appear.

### B. Adaptive Feature Reduction (AFR) using BFS and RST

FR is a vital process in ML pipelines, as it aims to cut down on the data dimensions without significantly affecting the model's performance. While several algorithms aim to do this, each has advantages and disadvantages. BFS is known for its ability to traverse the feature space optimally but can be computationally expensive. On the other hand, RST provides a formal framework to identify indispensable features but can be heuristic and computationally intensive for calculating reducts.

An adaptive approach that combines the strengths of both algorithms is thus conceived to achieve effective FR. The rationale is to employ RST's capability to identify core attributes indispensable for the DMS and then use BFS to navigate the feature space efficiently. In the given dataset $\mathcal{D}$, each feature subset $S \subseteq \mathcal{A}$ is a potential candidate for FR. These subsets are represented as nodes in the search space that BFS navigates. An evaluation function $f(S)$ is used to assess the "quality" of each subset $S$, analogous to how each node in a traditional BFS comes with an associated cost or value.

*1) Initialization using core attributes from RST:* Rough Set Theory first identifies a set of core attributes $\mathcal{R}_{core}$ from $\mathcal{A}$. These are the features that are indispensable for maintaining discernibility among the classes in $\mathcal{D}$ as shown in Eq. (19)

$$\mathcal{R}_{core} = \{a \in \mathcal{A} \mid a \text{ is indispensable for discernibility}\} \quad (19)$$

*2) Evaluation function in BFS:* The evaluation function $f(S)$ used in BFS combines a cost function $g(S)$ and a heuristic $h(S)$ to guide the search. $g(S)$ could represent how well $S$ performs in terms of model accuracy or any other metric, and $h(S)$ is a heuristic estimate of the "distance" to the optimal feature subset, see Eq. (20).

$$f(S) = \omega_1 \cdot g(S) + \omega_2 \cdot h(S) \quad (20)$$

Here, $\omega_1$ and $\omega_2$ are weight parameters.

*3) Priority assignment using RST:* During the BFS traversal, RST is used to identify if a subset $S$ is a reduct minimal set of features with discernibility power comparable to $\mathcal{A}$. Such subsets are flagged for higher priority in the BFS queue.

$$\text{Priority}(S_i) = \begin{cases} \alpha \cdot f(S_i), & \text{If } S_i \text{ is a reduct} \\ f(S_i), & \text{Otherwise} \end{cases} \quad (21)$$

In Eq. (21), $\alpha < 1$ is a factor that lowers the evaluation function $f(S_i)$ for reducts, they are effectively giving them a higher priority in the queue. By methodically integrating RST for initial setup and ongoing evaluation with the traversal capabilities of BFS, the algorithm aims to find an optimal and minimal feature subset from $\mathcal{A}$ for dataset $\mathcal{D}$. In the proposed algorithm, the focus is on reducing features by generating child nodes with fewer attributes, followed by an evaluation of their effectiveness using both BSF and RST techniques. Feature sets that neither improve nor degrade the quality of the model will be pruned. With this understanding now established, Algorithm 3, shown below, illustrates the steps involved:

*Algorithm 3 for BFS-RST based on Adaptive Feature Reduction*

*Input:*

- $\mathcal{F}$: *Complete set of features*

- $f(S)$: *Evaluation function for a feature subset $S$*

- $\mathcal{C}$ : *Stopping Criteria (e.g., a set limit on the number of features)*

*Output:*

- $\mathcal{S}_{opt}$ : *Optimal reduced set of features*

  *Initialize:*

- *Compute the core attributes $\mathcal{R}_{core}$ using RST. These are the features that are indispensable for the discernibility of classes.*
- *Initialize priority queue $Q$ with $\mathcal{R}_{core}$ as the root node, evaluated by $f(\mathcal{R}_{core})$.*
- *Algorithm Steps:*
  - *While $Q$ is not empty and $\mathcal{C}$ is not met, Do*
    - *Dequeue: Pop the node $S$ with the lowest $f(S)$ from $Q$.*

o   *Check Stopping Criteria:*
o   *If S satisfies C, Then*
o   *Return $S_{opt} = S$*
o   *Exit*
o   *FR and Child Node Generation:*
   ▪   *Remove one feature at a time from S to create smaller subsets $S_1, S_2, …, S_n$*
   ▪   *For Each $S_i$ , if $S_i$ is a reduct according to RST, flag it as a high-priority node.*

*Evaluate and Enqueue:*

- **For Each** *Child Node $S_i$, Compute $f(S_i)$*
- **If** *$S_i$ is flagged as high-priority, Adjust $f(S_i)$ to reflect its importance.*
- *Insert $S_i$ into Q*
- *Re-sort Priority Queue: Sort Q based on $f(S)$.*

In Step 3.3.1, each child node $S_i$ has one less feature than its parent $S$. This is where FR is explicitly done. Here, Rough Set Theory is used for two purposes:

(i)   *It provides a robust starting point $\mathcal{R}_{core}$ that contains indispensable features, ensuring that the essential features are not eliminated in the initial stages.*

(ii)   *It helps to flag high-priority nodes (reducts) during the FR process, guiding the algorithm toward a more meaningful feature subset.*

The BFS evaluates these smaller feature sets and prioritizes them in the queue. If a reduced feature set satisfies the stopping criteria, it is output as the optimal set of features $S_{opt}$ . In essence, this algorithm combines the strengths of both RST and BFS to perform feature reduction in a more effective and informed manner.

### C.  Dynamic Correlated Regularized Random  (DCRRF)

DCRRF is a novel hybrid model that aims to combine the strengths of Correlation-based Feature Selection (CFS) and Regularized Random Forest (RRF) to optimize FS and improve model performance dynamically. By incorporating CFS into the training of each tree within the RRF ensemble, DCRRF aims to maximize model robustness and interpretability. The model takes a reduced feature set $D'$ as input from the BFS-RST Adaptive algorithm. This feature set is standardized or normalized to make feature values comparable using the following steps:

*1) Standardization*: In the standardization process, every attribute is adjusted to have a zero mean and a unit standard deviation. This becomes particularly crucial when dealing with features in disparate units or varying in scale. To standardize a given feature $x$, a commonly used mathematical EQU (22) is typically employed.

$$Standardized(x) = \frac{x - mean(x)}{std(x)} \quad (22)$$

*2) Normalization*: In normalization, the features are typically scaled to lie in a given range [0,1]. This is often beneficial when the algorithm involves distance metrics or when the feature has a skewed distribution. Normalization of a feature $x$ is generally achieved by Eq. (23):

$$Normalized (x) = \frac{x - \min(x)}{\max(x) - \min(x)} \quad (23)$$

The normalized feature set is the foundation for the subsequent feature selection process in the DCRRF model. For each tree $T_m$ in the ensemble, a distinct bootstrap sample $D'_m$ is chosen from this processed feature set. A correlation matrix $Corr(D'_m)$ is then computed for each of these samples, expressed as in Eq. (24).

$$Corr(D_m) = \begin{pmatrix} corr(X_1, X_1) & corr(X_1, X_2) & \cdots & corr(X_1, X_n) \\ corr(X_2, X_1) & corr(X_2, X_2) & \cdots & corr(X_2, X_n) \\ \vdots & \vdots & \ddots & \vdots \\ corr(X_n, X_1) & corr(X_n, X_2) & \cdots & corr(X_n, X_n) \end{pmatrix} \quad (24)$$

Using the CFS criterion $Cr$, a tailored feature subset $F_m$ is dynamically selected for each tree $T_m$. The $Cr_m$ The criterion is calculated as Eq. (25).

$$Cr_m \frac{k_m \cdot \overline{\tau_{cf_m}}}{\sqrt{k_m + k_m \cdot (k_m - 1) \cdot \overline{r_{ff_m}}}}, \quad (25)$$

where, $k_m$ is the number of features in $F_m$, $\overline{\tau_{cf_m}}$ is the average correlation between features and the class label for $D'_m$, and $\overline{r_{ff_m}}$ is the average inter-feature correlation for $D'_m$. This criterion $Cr_m$ is used to select an optimal subset of features $F_m$ for each $T_m$. After this dynamic FS, each tree $T_m$ is trained using its respective selected feature subset $F_m$. The training process adopts the regularized objective function which is shown in Eq. (26).

$$(T_{m,F_m}) = Impurity(T_{m,F_m}) + \lambda Complexity(T_{m,F_m}) \quad (26)$$

Importantly, this objective function is indexed with $F_m$ to signify the dynamically chosen features for that specific tree. The optimal feature set $F^*$ is then determined by an intersection operation over all the dynamically selected feature subsets $F_m$. This can be formally expressed as in Eq. (27).

$$F^* = F_1 \cap F_2 \cap … \cap F_M \quad (27)$$

The dynamic FS introduces diversity among the individual trees, making the ensemble model more resilient and adaptable. It also enables optimized FS, thereby potentially improving both performance and interpretability. The following Algorithm 4 presents the steps involved in the proposed FSM.

### D. Algorithm 4 for DCRRF for Feature selection

*Input:*

- *Reduced Feature set D'*

- *Number of trees M*

- *Regularization parameter λ*

*Output*

- *Optimal set of features $F^*$*

  - *Data Preprocessing*
  - *Normalize or standardize the Feature set $D'$.*

- *Initialize Feature Set*
- *Initialize feature set $F^* = \emptyset$.*

*Ensemble Training and FS*

- *For $m = 1$ to M do the following:*
- *Bootstrap Sample*
- *Draw a bootstrap sample $D'_m$ from $D'$.*
- *Calculate Correlation Matrix*
- *Compute $Corr(D'_m)$ for the bootstrap sample $D'_m$.*
- *FS with CFS*
- *Compute the CFS criterion $Cr_m$ using $Corr(D'_m)$.*
- *Select the optimal feature subset $F_m$ based on $Cr_m$.*
- *Train Regularized RF Tree*
- *Use $F_m$ and $D'_m$ to train a tree $T_m$ with the objective function:*

$$Objective(T_{m,F_m})$$
$$= Impurity(T_{m,F_m})$$
$$+ \lambda\,Complexity(T_{m,F_m})$$

- *Update Feature Aggregation*
- *Update $F^*$ based on $F_m$ using an intersection operation: $F^* = F^* \cap F_m$.*
- *Determine the Optimal Feature Set*

- *Return $F^*$ as the optimal feature set that captures the most important features across the ensemble.*

*D. Data Analysis*

The data analysis phase serves as the final phase of the FSM's pipeline. This phase is significant because it provides the final validation of the feature sets that have been carefully reduced and selected through the preceding stages. The focus here is on evaluating these feature sets within the specific context of the problem, be it classification, clustering, or some other form of ML task. For the purpose of this paper, the efficacy of the proposed FR and FS model is examined using a SVM classifier. The reason for choosing SVM for analysis is twofold. First, SVMs are known for their effectiveness in high-dimensional spaces, making them a suitable choice for testing the quality of the FS. Second, SVMs are robust to overfitting, especially in cases where the number of dimensions is greater than the number of samples, further validating the quality of the FS. The features that have passed through the BFS-RST Adaptive Algorithm and the DCRRF are fed into the SVM model. Performance metrics such as accuracy, precision, recall, and F1-score are computed to evaluate the classifier's performance on the selected feature sets.

## V. EXPERIMENTAL ANALYSIS

*A. Dataset and Implementation*

In the current research, experiments were conducted on four gene expression datasets analyzed by [59], namely: i) Prostate [60], ii) Brain [61], iii) NCI60 [62] and iv) Adenocarcinoma [63]. The specifics regarding the number of instances and attributes for each dataset are detailed in Table. I. All methods and experimental procedures were executed in a Jupyter Notebook environment, utilizing the Python 3.6 language. Computations and tests were carried out on a system equipped with a Windows 10 operating system, powered by a 2.8GHz AMD Ryzen 5 processor, and supplemented by 8GB RAM. Various stages of data processing, feature selection, and machine learning implementations leveraged pre-existing software libraries.

The datasets mentioned above are partitioned into an 80:20 ratio for the purposes of training and evaluation. The SVM model is calibrated using specific hyperparameter settings, as shown in Table II, for optimal performance.

The regularization parameter C is set to 1 to maintain a compromise between maximizing the margin and minimizing the classification error. The Radial Basis Function (RBF) kernel is chosen for its ability to handle both linear and nonlinear patterns in the data [64-73]. The model undergoes 100 iterations during training to ensure convergence and optimal performance. The performance of the proposed feature selection model is compared with RF-based baseline models such as i) Boruta, ii) RRF, iii) VSURF and iv) GRRF. The effectiveness of the SVM, when employing each feature mentioned above, FSM, is assessed through metrics such as accuracy, sensitivity, specificity, precision, and F-score. The results achieved by all the models for the listed performance metrics are shown in Table III.

TABLE I. DATASET DESCRIPTION

| Dataset | Instance | Attribute | Class |
|---|---|---|---|
| Prostate | 102 | 6033 | 2 |
| Brain | 42 | 5597 | 5 |
| nci60 | 61 | 5244 | 8 |
| Adenocarcinoma | 76 | 9868 | 2 |

TABLE II. SVM LEARNING PARAMETERS

| Hyperparameter | Specific Value |
|---|---|
| Regularization C | 1 |
| Kernel Type | RBF |
| Number of Iterations | 100 |

TABLE III.    PERFORMANCE COMPARISON FOR DIFFERENT BASELINES AGAINST FOUR DATASETS

| Models | FS | Accuracy | Sensitivity | Specificity | Precision | F1-score |
|---|---|---|---|---|---|---|
| **Prostate Dataset (No. of Features: 6033)** | | | | | | |
| **Boruta** | 96 | 0.9306 | 0.9242 | 0.9558 | 0.9579 | 0.9407 |
| **RRF** | 88 | 0.9479 | 0.9413 | 0.9558 | 0.9581 | 0.9496 |
| **VSURF** | 78 | 0.9385 | 0.9356 | 0.9421 | 0.9466 | 0.9411 |
| **GRRF** | 18 | 0.9488 | 0.9518 | 0.9557 | 0.9572 | 0.9497 |
| **DCRRF** | 29 | 0.9514 | 0.9582 | 0.9559 | 0.9582 | 0.9534 |
| **BFSRST+ DCRRF** | 12 | 0.9544 | 0.9589 | 0.9593 | 0.9625 | 0.9562 |
| **Brain Dataset (No. of Features: 5597)** | | | | | | |
| **Boruta** | 83 | 0.8761 | 0.8464 | 0.8990 | 0.8464 | 0.8464 |
| **RRF** | 97 | 0.8861 | 0.8236 | 0.9342 | 0.8797 | 0.8507 |
| **VSURF** | 56 | 0.9060 | 0.8693 | 0.9342 | 0.8882 | 0.8787 |
| **GRRF** | 22 | 0.8960 | 0.8693 | 0.9166 | 0.8693 | 0.8693 |
| **DCRRF** | 28 | 0.9073 | 0.8802 | 0.9292 | 0.8986 | 0.8894 |
| **BFSRST+ DCRRF** | 19 | 0.9126 | 0.9096 | 0.9114 | 0.8910 | 0.9003 |
| **NCI60 Dataset (No. of Features: 5244)** | | | | | | |
| **Boruta** | 93 | 0.8794 | 0.9004 | 0.9257 | 0.9660 | 0.8408 |
| **RRF** | 197 | 0.9157 | 0.8823 | 0.9414 | 0.8823 | 0.8823 |
| **VSURF** | 83 | 0.8878 | 0.7351 | 0.9549 | 0.9485 | 0.8283 |
| **GRRF** | 63 | 0.9233 | 0.8598 | 0.9680 | 0.9075 | 0.8830 |
| **DCRRF** | 58 | 0.9283 | 0.8765 | 0.9405 | 0.9008 | 0.8885 |
| **BFSRST+ DCRRF** | 53 | 0.9317 | 0.8960 | 0.9317 | 0.8960 | 0.8960 |
| **Adenocarcinoma Dataset (No. of Features: 9868)** | | | | | | |
| **Boruta** | 143 | 0.8757 | 0.8027 | 0.9532 | 0.9485 | 0.8695 |
| **RRF** | 86 | 0.9098 | 0.8933 | 0.9274 | 0.9290 | 0.9108 |
| **VSURF** | 106 | 0.8784 | 0.7844 | 0.9781 | 0.9712 | 0.8679 |
| **GRRF** | 20 | 0.9057 | 0.9268 | 0.9785 | 0.9768 | 0.9030 |
| **DCRRF** | 36 | 0.9101 | 0.8977 | 0.9367 | 0.9274 | 0.8992 |
| **BFSRST+ DCRRF** | 14 | 0.9249 | 0.9130 | 0.9387 | 0.9405 | 0.9179 |

In both the Prostate and Brain datasets, as shown in Fig. 2 and Fig. 3, DCRRF demonstrates superior performance across multiple metrics. For the Prostate dataset, DCRRF achieves an accuracy of 0.9514, edging out the second-best model, RRF, by 0.37%. It also excels in sensitivity with a score of 0.9582, which is notably higher than RRF's 0.9413. Regarding specificity and precision, DCRRF performs on par with RRF and GRRF, highlighting its balanced efficiency in identifying True Negatives (TN) and minimizing False Positives (FP). The F1-score for DCRRF is the highest at 0.9534, and it further improves to 0.9562 when augmented with BFS-RST, all while requiring only 12 selected features. For the Brain dataset, DCRRF again leads in accuracy and sensitivity, with scores of 0.9073 and 0.8802, respectively. While its specificity score of 0.9292 is not the highest, it still indicates a balanced

performance compared to RRF's higher specificity but lower sensitivity. In the precision metric, DCRRF is slightly edged out by VSURF but still performs strongly with a score of 0.8986. Its F1-score stands at 0.8894, and when combined with BFS-RST, it further improves to 0.9003, again achieving this with fewer features. These metrics collectively indicate that DCRRF, particularly when enhanced with BFS-RST, offers balanced, efficient, and robust performance across both datasets in FS and classification tasks.

In the NCI60 dataset, as shown in Fig. 4, DCRRF stands out with an accuracy of 0.9283, outperforming the next-best model, RRF, which scores 0.9157. While its sensitivity score of 0.8765 isn't the highest, it's balanced by a strong specificity of 0.9405. The model's F1-score is 0.8885, which is superior to both Boruta's 0.8408 and RRF's 0.8823. Its precision score

of 0.9008 is commendable, though it is slightly eclipsed by Boruta's 0.9660. Notably, when integrated with BFS-RST, the model's F1-score rises to 0.8960 with a reduced feature count of 53. In the Adenocarcinoma dataset, as shown in Fig. 5, DCRRF maintains its strong performance with an accuracy of 0.9101, closely followed by RRF at 0.9098. DCRRF shines in sensitivity with a score of 0.8977, substantially better than Boruta's 0.8027 and slightly edging out RRF's 0.8933. With well-rounded scores in specificity (0.9367) and precision (0.9274), it also maintains a balanced F1-score of 0.8992. When enhanced by BFS-RST, the F-score improves to 0.9179 with just 14 FS, demonstrating the model's efficiency and efficacy in FS and classification.

In a comprehensive review of the results for OOB error, time consumption and AUC efficiently, as shown in Fig. 6 to Fig. 8, BFSRST+DCRRF consistently delivers outstanding performance across all datasets, excelling in AUC and minimizing OOB errors. For instance, in the Prostate dataset, this model achieves the highest AUC of 0.893, using the fewest features (12) and an OOB error of just 0.11. The computational time, although slightly higher than its DCRRF counterpart, remains modest at 0.06 minutes. Similarly, in the Brain and NCI60 datasets, BFSRST+DCRRF again tops the chart in AUC, recording 0.911 and 0.914, respectively, while maintaining low OOB errors and computational times. On the Adenocarcinoma dataset, it achieves an AUC of 0.902, leading the pack. VSURF performs well but is computationally expensive, particularly noticeable in the Prostate and Adenocarcinoma datasets, where the computational times are 0.08 and 0.1 minutes, respectively. DCRRF alone also shows promise, particularly in the NCI60 and Adenocarcinoma datasets, where it nearly matches the performance of its BFSRST-enhanced version but with more features. Boruta and RRF, although competent, generally lag in AUC and OOB error metrics. Notably, GRRF consistently demands fewer features but doesn't offer a compelling trade-off regarding AUC or OOB error. The BFSRST+DCRRF model demonstrates superior, balanced performance across all four datasets.



Fig. 2. Performance comparison for prostate dataset.
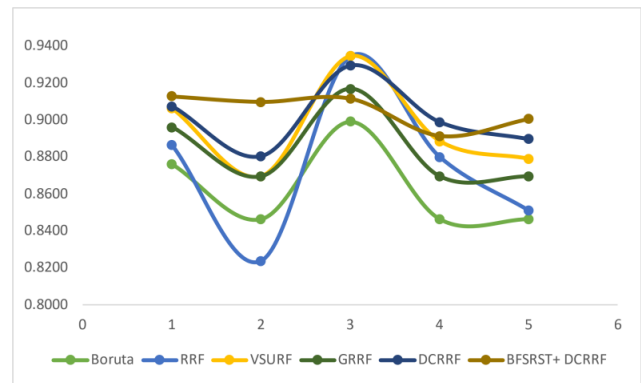


Fig. 3. Performance comparison for brain dataset.
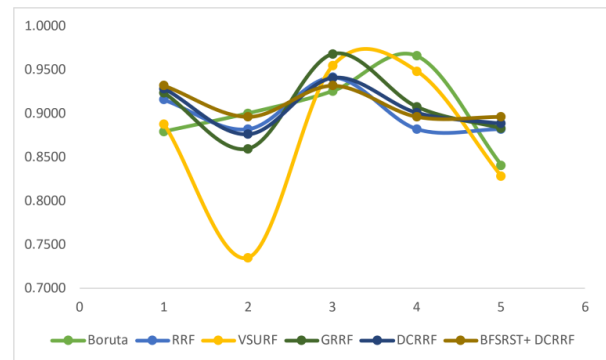


Fig. 4. Performance comparison for NCI60 dataset.
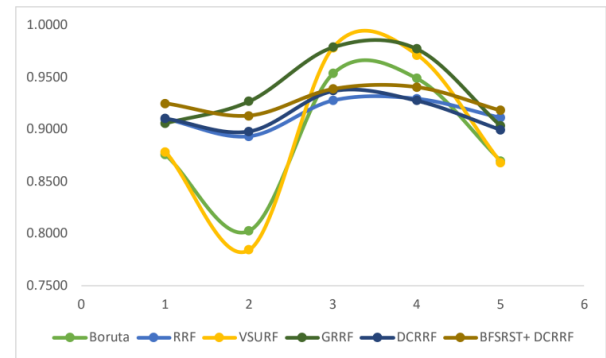


Fig. 5. Performance comparison for adenocarcinoma dataset.
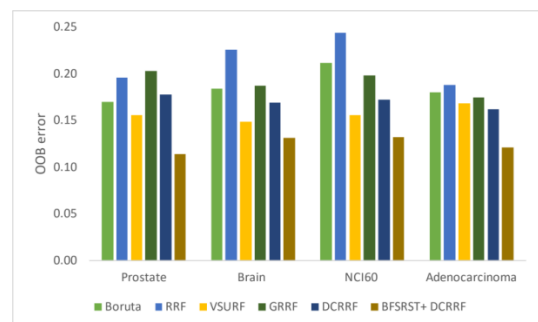


Fig. 6. OOB error comparison.
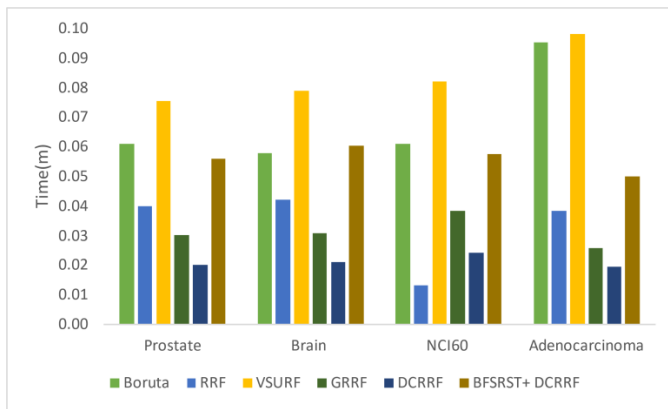
Fig. 7.    FS-time comparison.
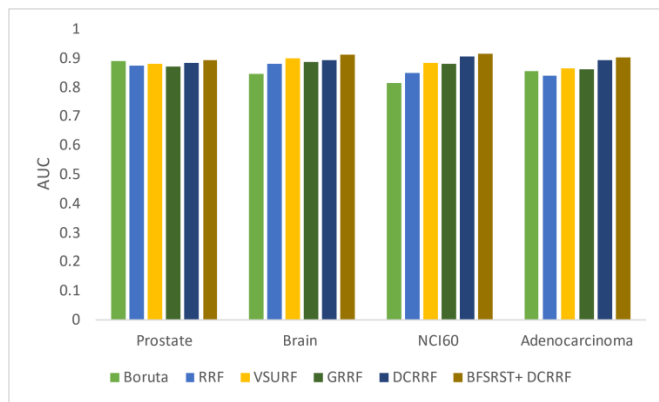


Fig. 8.    AUC comparison.

## VI.  CONCLUSION

Handling big data with high dimensions presents unique challenges, particularly regarding computational resources and predictive accuracy. To address these issues, an all-encompassing Feature Selection Model (FSM) has been developed. This system incorporates initial data cleaning and feature reduction through Best-first Search and Rough Set Theory (BFS-RST). It culminates in deploying a specialized Random Forest (RF) algorithm called Dynamic Correlated Regularized Random Forest (DCRRF). Each stage of this four-tiered architecture serves a specific function, from initial data refinement to advanced FSM. The final assessment phase employs a Support Vector Machine (SVM) classifier to evaluate the quality and utility of the selected features rigorously. When tested against existing RF-based FSM on four gene expression datasets, this innovative approach improved computational efficiency and classification accuracy. The system's enhanced performance indicates its potential as a scalable solution for tackling the unique challenges presented by high-dimensional big data across various applications.

## FUNDING STATEMENT

## REFERENCES

[1]  E. Debie and K. Shafi, Implications of the curse of dimensionality for supervised learning classifier systems: theoretical and empirical analyses. Pattern Analysis and Applications, vol. 22, pp. 519-536, 2019.

[2]  S. Shi, Y. Xu, X. Xu, X. Mo and J. Ding, A Preprocessing Manifold Learning Strategy Based on t-Distributed Stochastic Neighbor Embedding. Entropy, vol. 25, no. 7, pp:1065, 2023.

[3]  C. Kern, T. Klausch and F. Kreuter, Tree-based Machine Learning Methods for Survey Research. Surv Res Methods, vol. 13, no. 1, pp. 73-93, 2019.

[4]  F. Tang and H. Ishwaran, Random forest missing data algorithms. Statistical Analysis and Data Mining: The ASA Data Science Journal, vol. 10, no. 6, pp. 363-377, 2017.

[5]  S. Georganos, T. Grippa, S. Vanhuysse, M. Lennert, M. Shimoni, S. Kalogirou and E. Wolff, Less is more: Optimizing classification performance through feature selection in a very-high-resolution remote sensing object-based urban application. GIScience & remote sensing, vol. 55, no. 2, pp. 221-242, 2018.

[6]  M. B. Kursa and W. R. Rudnicki, Feature selection with the Boruta package. Journal of statistical software, vol. 36, pp. 1-13, 2010.

[7]  T. Hothorn, K. Hornik and A. Zeileis, Unbiased recursive partitioning: A conditional inference framework. Journal of Computational and Graphical Statistics, vol. 15, no. 3, pp. 651-674, 2006.

[8]  H. Deng and G. Runger, Feature selection via regularized trees. International Joint Conference on Neural Networks (IJCNN), pp. 1-8, 2012.

[9]  P. Geurts, D. Ernst, L. Wehenkel, Extremely randomized trees. Machine learning, vol. 63, pp. 3-42, 2006.

[10] M. A. M. Hasan, M. Nasser, S. Ahmad and K. I. Molla, Feature selection for intrusion detection using random forest. Journal of information security, vol. 7, no. 3, pp. 129-140, 2016.

[11] M. Huljanah, Z. Rustam, S. Utama and T. Siswantining, Feature selection using random forest classifier for predicting prostate cancer. In IOP Conference Series: Materials Science and Engineering, vol. 546, no. 5, p. 052031, IOP Publishing, 2019.

[12] Y. Wang, Y. Xu, Z. Yang, X. Liu and Q. Dai, Using recursive feature selection with random forest to improve protein structural class prediction for low-similarity sequences. Computational and Mathematical Methods in Medicine, 2021.

[13] A. Behnamian, K. Millard, S. N. Banks, L. White, M. Richardson and J. Pasher, A systematic approach for variable selection with random forests: achieving stable variable importance values. IEEE Geoscience and Remote Sensing Letters, vol. 14, no. 11, pp. 1988-1992, 2017.

[14] M. Rostami and M. Oussalah, A novel explainable COVID-19 diagnosis method by integration of feature selection with random forest. Informatics in Medicine Unlocked, vol. 30, no. 100941, 2022.

[15] E. V. Sylvester, P. Bentzen, I. R. Bradbury, M. Clément, J. Pearce, J. Horne and R. G. Beiko, Applications of random forest feature selection for fine-scale genetic population assignment. Evolutionary Applications, vol. 11, no. 2, pp. 153-165, 2018.

[16] X. Li, W. Chen, Q. Zhang and L. Wu, Building auto-encoder intrusion detection system based on random forest feature selection. Computers & Security, vol. 95, no. 101851, 2020.

[17] H. Fei, Z. Fan, C. Wang, N. Zhang, T. Wang, R. Chen and T. Bai, Cotton classification method at the county scale based on multi-features and random forest feature selection algorithm and classifier. Remote Sensing, vol. 14, no. 4, pp. 829, 2022.

[18] Z. Pawlak, Rough set theory and its applications to data analysis. *Cybernetics & Systems*, vol. *29, no.* 7, pp. 661-688, 1998.

[19] T. Kavitha *et al.*, 'Deep Learning Based Capsule Neural Network Model for Breast Cancer Diagnosis Using Mammogram Images', *Interdisciplinary Sciences – Computational Life Sciences*, vol. 14, no. 1, pp. 113–129, 2022.

[20] S. Sengan, O. I. Khalaf, P. Vidya Sagar, D. K. Sharma, L. Arokia Jesu Prabhu, and A. A. Hamad, 'Secured and privacy-based IDS for healthcare systems on e-medical data using machine learning approach', *International Journal of Reliable and Quality E-Healthcare*, vol. 11, no. 3, 2022.

[21] S. Namasudra, R. Chakraborty, A. Majumder, and N. R. Moparthi, 'Securing Multimedia by Using DNA-Based Encryption in the Cloud Computing Environment', *ACM Transactions on Multimedia Computing, Communications and Applications*, vol. 16, no. 3s, 2021.

[22] K. K. D. Ramesh, G. Kiran Kumar, K. Swapna, D. Datta, and S. Suman Rajesh, 'A review of medical image segmentation algorithms', *EAI Endorsed Transactions on Pervasive Health and Technology*, vol. 7, no. 27, 2021.

[23] A. Naik, S. C. Satapathy, and A. Abraham, 'Modified Social Group Optimization—a meta-heuristic algorithm to solve short-term hydrothermal scheduling', *Applied Soft Computing Journal*, vol. 95, 2020.

[24] N. Satheesh *et al.*, 'Flow-based anomaly intrusion detection using machine learning model with software-defined networking for OpenFlow network', *Microprocessors and Microsystems*, vol. 79, 2020.

[25] K. N. Dattatraya and K. R. Rao, 'Hybrid based cluster head selection for maximizing network lifetime and energy efficiency in WSN', *Journal of King Saud University - Computer and Information Sciences*, vol. 34, no. 3, pp. 716–726, 2022.

[26] N. Yuvaraj, T. Karthikeyan, and K. Praghash, 'An Improved Task Allocation Scheme in Serverless Computing Using Gray Wolf Optimization (GWO) Based Reinforcement Learning (RIL) Approach', *Wireless Personal Communications*, vol. 117, no. 3, pp. 2403–2421, 2021.

[27] C. Sridhar, P. K. Pareek, R. Kalidoss, S. S. Jamal, P. K. Shukla, and S. J. Nuagah, 'Optimal Medical Image Size Reduction Model Creation Using Recurrent Neural Network and GenPSOWVQ', *Journal of Healthcare Engineering*, vol. 2022, 2022.

[28] S. Deshmukh, K. Thirupathi Rao, and M. Shabaz, 'Collaborative Learning Based Straggler Prevention in Large-Scale Distributed Computing Framework', *Security and Communication Networks*, vol. 2021, 2021.

[29] P. K. Pareek *et al.*, 'IntOPMICM: Intelligent Medical Image Size Reduction Model', *Journal of Healthcare Engineering*, vol. 2022, 2022.

[30] S. Mishra, L. Jena, H. K. Tripathy, and T. Gaber, 'Prioritized and predictive intelligence of things enabled waste management model in smart and sustainable environment', *PLoS ONE*, vol. 17, no. 8, 2022.

[31] S. Stalin *et al.*, 'A Machine Learning-Based Big EEG Data Artifact Detection and Wavelet-Based Removal: An Empirical Approach', *Mathematical Problems in Engineering*, vol. 2021, 2021.

[32] C. Banchhor and N. Srinivasu, 'Integrating Cuckoo search-Grey wolf optimization and Correlative Naive Bayes classifier with Map Reduce model for big data classification', *Data and Knowledge Engineering*, vol. 127, 2020.

[33] K. Saikumar, V. Rajesh, and B. S. Babu, 'Heart Disease Detection Based on Feature Fusion Technique with Augmented Classification Using Deep Learning Technology', *Treatment du Signal*, vol. 39, no. 1, pp. 31–42, 2022.

[34] S. D. M. Achanta, T. Karthikeyan, and R. Vinoth Kanna, 'A wireless IoT system towards gait detection technique using FSR sensor and wearable IoT devices', *International Journal of Intelligent Unmanned Systems*, vol. 8, no. 1, pp. 43–54, 2020.

[35] S. Sengan, G. R. K. Rao, O. I. Khalaf, and M. R. Babu, 'Markov mathematical analysis for comprehensive real-time data-driven in healthcare', *Mathematics in Engineering, Science and Aerospace*, vol. 12, no. 1, pp. 77–94, 2021.

[36] V. Kumar *et al.*, 'Addressing Binary Classification over Class Imbalanced Clinical Datasets Using Computationally Intelligent Techniques', *Healthcare (Switzerland)*, vol. 10, no. 7, 2022.

[37] S. Kumar, A. Jain, A. Kumar Agarwal, S. Rani, and A. Ghimire, 'Object-Based Image Retrieval Using the U-Net-Based Neural Network', *Computational Intelligence and Neuroscience*, vol. 2021, 2021.

[38] M. S. Mekala and P. Viswanathan, '(t,n): Sensor Stipulation with THAM Index for Smart Agriculture Decision-Making IoT System', *Wireless Personal Communications*, vol. 111, no. 3, pp. 1909–1940, 2020.

[39] P. Sharma, N. R. Moparthi, S. Namasudra, V. Shanmuganathan, and C.-H. Hsu, 'Blockchain-based IoT architecture to secure healthcare system using identity-based encryption', *Expert Systems*, vol. 39, no. 10, 2022.

[40] S. Joshi *et al.*, 'Unified Authentication and Access Control for Future Mobile Communication-Based Lightweight IoT Systems Using Blockchain', *Wireless Communications and Mobile Computing*, vol. 2021, 2021.

[41] M. Baskar, J. Ramkumar, C. Karthikeyan, V. Anbarasu, A. Balaji, and T. S. Arulananth, 'Low rate DDoS mitigation using real-time multi-threshold traffic monitoring system', *Journal of Ambient Intelligence and Humanized Computing*, 2021.

[42] A. V. N. Reddy, C. P. Krishna, and P. K. Mallick, 'An image classification framework exploring the capabilities of extreme learning machines and artificial bee colony', *Neural Computing and Applications*, vol. 32, no. 8, pp. 3079–3099, 2020.

[43] C. Banchhor and N. Srinivasu, 'Integrating Cuckoo search-Grey wolf optimization and Correlative Naive Bayes classifier with Map Reduce model for big data classification', *Data and Knowledge Engineering*, vol. 127, 2020.

[44] V. Talasila, K. Madhubabu, M. C. Mahadasyam, N. J. Atchala, and L. S. Kande, 'The prediction of diseases using rough set theory with recurrent neural network in big data analytics', *International Journal of Intelligent Engineering and Systems*, vol. 13, no. 5, pp. 10–18, 2020.

[45] S. P. Praveen, T. B. Murali Krishna, C. H. Anuradha, S. R. Mandalapu, P. Sarala, and S. Sindhura, 'A robust framework for handling health care information based on machine learning and big data engineering techniques', *International Journal of Healthcare Management*, 2022.

[46] C. Banchhor and N. Srinivasu, 'FCNB: Fuzzy Correlative Naive Bayes Classifier with MapReduce Framework for Big Data Classification', *Journal of Intelligent Systems*, vol. 29, no. 1, pp. 994–1006, 2020.

[47] C. Banchhor and N. Srinivasu, 'Analysis of Bayesian optimization algorithms for big data classification based on Map Reduce framework', *Journal of Big Data*, vol. 8, no. 1, 2021.

[48] A. D. Jadhav and V. Pellakuri, 'Highly accurate and efficient two phase-intrusion detection system (TP-IDS) using distributed processing of HADOOP and machine learning techniques', *Journal of Big Data*, vol. 8, no. 1, 2021.

[49] A. V. Brahmane and C. B. Krishna, 'Rider chaotic biography optimization-driven deep stacked auto-encoder for big data classification using spark architecture: Rider chaotic biography optimization', *International Journal of Web Services Research*, vol. 18, no. 3, pp. 42–62, 2021.

[50] K. Jammalamadaka and N. Parveen, 'Testing coverage criteria for optimized deep belief network with search and rescue', *Journal of Big Data*, vol. 8, no. 1, 2021.

[51] S. K. Funde and G. Swain, 'Security aware information classification in health care big data', *International Journal of Electrical and Computer Engineering*, vol. 11, no. 5, pp. 4439–4448, 2021.

[52] S. Roy, B. Patel, D. Bhattacharyya, K. Dhayal, T.-H. Kim, and M. Mittal, 'Demographic gender prediction of Twitter users using big data analytics: An application of decision marketing', *International Journal of Reasoning-based Intelligent Systems*, vol. 13, no. 2, pp. 41–49, 2021.

[53] C. Banchhor and N. Srinivasu, 'Holoentropy based Correlative Naive Bayes classifier and MapReduce model for classifying the big data', *Evolutionary Intelligence*, vol. 15, no. 2, pp. 1037–1050, 2022.

[54] C. Banchhor and N. Srinivasu, 'Grey Wolf Shuffled Shepherd Optimization Algorithm-Based Hybrid Deep Learning Classifier for Big Data Classification', *International Journal of Swarm Intelligence Research*, vol. 13, no. 1, 2022.

[55] S. Funde and G. Swain, 'Big Data Privacy and Security Using Abundant Data Recovery Techniques and Data Obliviousness Methodologies', *IEEE Access*, vol. 10, pp. 105458–105484, 2022.

[56] C. Banchhor and N. Srinivasu, 'A comprehensive study of data intelligence in the context of big data analytics', *Web Intelligence*, vol. 20, no. 1, pp. 53–66, 2022.

[57] A. V. Brahmane and B. C. Krishna, 'Big data classification using deep learning and Apache spark architecture', *Neural Computing and Applications*, vol. 33, no. 22, pp. 15253–15266, 2021.

[58] A. V. Brahmane and B. C. Krishna, 'DSAE-Deep Stack Auto Encoder and RCBO-Rider Chaotic Biogeography Optimization Algorithm for Big Data Classification', *Advances in Parallel Computing*, vol. 39, pp. 213–227, 2021.

[59] R. Díaz-Uriarte and S. Alvarez de Andrés, Gene selection and classification of microarray data using random forest. *BMC Bioinformatics*, vol. 7, pp. 1-13, 2006.

[60] D. Singh, P. G. Febbo, K. Ross, D. G. Jackson, J. Manola, C. Ladd and W. R. Sellers, Gene expression correlates of clinical prostate cancer behaviour. *Cancer Cell*, vol. *1*, no. 2, pp. 203-209, 2022.

[61] S. L. Pomeroy, P. Tamayo, M. Gaasenbeek, L. M. Sturla, M. Angelo, M. E. McLaughlin and T. R. Golub, Prediction of central nervous system embryonal tumour outcome based on gene expression. *Nature*, vol. *415, no.* 6870, pp. 436-442, 2002.

[62] D. T. Ross, U. Scherf, M. B. Eisen, C. M. Perou, C. Rees, P. Spellman and P. O. Brown, Systematic variation in gene expression patterns in human cancer cell lines. *Nature Genetics*, vol. *24, no.* 3, pp. 227-235, 2000.

[63] S. Ramaswamy, K. N. Ross, E. S. Lander and T. R. Golub, A molecular signature of metastasis in primary solid tumours. *Nature Genetics*, vol. *33*, no. 1, pp. 49-54, 2003.

[64] P. Sharma, N. R. Moparthi, S. Namasudra, V. Shanmuganathan, and C.-H. Hsu, 'Blockchain-based IoT architecture to secure healthcare system using identity-based encryption', *Expert Systems*, vol. 39, no. 10, 2022.

[65] S. Joshi *et al.*, 'Unified Authentication and Access Control for Future Mobile Communication-Based Lightweight IoT Systems Using Blockchain', *Wireless Communications and Mobile Computing*, vol. 2021, 2021.

[66] P. Chithaluru, F. Al-Turjman, T. Stephan, M. Kumar, and L. Mostarda, 'Energy-efficient blockchain implementation for Cognitive Wireless Communication Networks (CWCNs)', *Energy Reports*, vol. 7, pp. 8277–8286, 2021.

[67] N. Yuvaraj, K. Praghash, R. A. Raja, and T. Karthikeyan, 'An Investigation of Garbage Disposal Electric Vehicles (GDEVs) Integrated with Deep Neural Networking (DNN) and Intelligent Transportation System (ITS) in Smart City Management System (SCMS)', *Wireless Personal Communications*, vol. 123, no. 2, pp. 1733–1752, 2022.

[68] M. Z. U. Rahman, S. Surekha, K. P. Satamraju, S. S. Mirza, and A. Lay-Ekuakille, 'A Collateral Sensor Data Sharing Framework for Decentralized Healthcare Systems', *IEEE Sensors Journal*, vol. 21, no. 24, pp. 27848–27857, 2021.

[69] S. Sekar *et al.*, 'Autonomous Transaction Model for E-Commerce Management Using Blockchain Technology', *International Journal of Information Technology and Web Engineering*, vol. 17, no. 1, 2022.

[70] S. R. Dasari, S. Tondepu, L. R. Vadali, and N. Seelam, 'PEG-400 mediated an efficient eco-friendly synthesis of new isoxazolyl pyrido[2,3-d] pyrimidines and their anti-inflammatory and analgesic activity', *Synthetic Communications*, pp. 2950–2961, 2020.

[71] S. Rajasoundaran *et al.*, 'Secure watchdog selection using intelligent key management in wireless sensor networks', *Materials Today: Proceedings*, 2021.

[72] N. V. Rani and K. Ravindhranath, 'PEG-400 promoted a simple, efficient and eco-friendly synthesis of functionalized novel isoxazolyl pyrido[2,3-d]pyrimidines and their antimicrobial and anti-inflammatory activity', *Synthetic Communications*, vol. 51, no. 8, pp. 1171–1183, 2021.

[73] A. Bhattacharjya, 'A Holistic Study On The Use Of Blockchain Technology In CPS And IoT Architectures Maintaining The Cia Triad In Data Communication', *International Journal of Applied Mathematics and Computer Science*, vol. 32, no. 3, pp. 403–413, 2022.

# Fortifying Against Cyber Fraud: Instrument Development with the Protection Motivation Theory

Norhasyimatul Naquiah Ghazali, Syahida Hassan, Rahayu Ahmad
School of Computing, Universiti Utara Malaysia (UUM), Kedah, Malaysia

*Abstract*—Cybersecurity has become a trending topic in this technological era. Crimes keep happening in this medium and bring challenges for researchers and IT professionals worldwide to find the best solution to overcome this issue. Crimes primarily related to fraud on e-services have become a red alert that needs to be a concern for netizens. Instead of simply believing in the human-created network and system, individuals or users should acquire and implement protective behaviours for themselves. Thus, a few factors such as source credibility, perceived value of data, wishful thinking, perceived threat severity, perceived threat vulnerability, maladaptive rewards, and response efficacy have been investigated in this study, and the Protection Motivation Theory is used to counter cybersecurity issues faced by users. A tool has been created to facilitate the collection of empirical data necessary for verifying the proposed model. Analysis such as Content validity index (CVI) and Scale-level CVI (S-CVI) have been used to validate the item. The findings indicate that one of the items does not meet the criteria, however, it has been suggested by experts to revise and make it comprehensible to use for the main study. This paper also includes a discussion part regarding the implications of the experts' evaluation. This study, in particular, can help boost the understanding of cyber fraud and the proper methods, a user can employ to avoid becoming a victim.

*Keywords*—*Cyber security; cyber fraud; e-services; instrument development; content validity; Protection Motivation Theory (PMT)*

## I. INTRODUCTION

Nowadays, people live in a networked culture where cyber technology has enabled cloud computing, online shopping, and other activities [1]. Despite the various advantages of technology in terms of commerce, communication, education, and entertainment, as noted by Bulgurcu et al. [2], it also presents some drawbacks. The unbridled expansion of digital technology has contributed to the correspondingly burgeoning problem of cyber fraud. This development is inextricably linked to intricate complications and perils that are engendered by the anonymous and rapid nature of the internet, which has been mentioned by Khalifa et al. [3] resulting in an ever-widening conundrum of cyber criminality. Annually, Kuru and Bayraktar [4] stated that cybercriminals devise novel tactics and techniques to deceive potential targets. People around the world are concerned about various issues due to cyber fraud [5], which also occurs in Malaysia. Although many countries have taken steps to make the cyber world more secure, Sorell and Whitty [6] agreed that there is still much work to be done to find a long-term solution to the security issues that plague cyberspace.

In the meantime, some consumers are unaware that they use e-services in their everyday lives. e-Services, which encompass all electronic services such as online bill-paying applications, government e-services, online banking, and online shopping [7] make it easier for users to conduct any online activity. Although the government of Malaysia has put in place various controls and safeguards to protect its citizens online, the rate at which cybercrimes are committed continues to rise in tandem. For instance, in 2022, there were 4,912 reported cases of the Macau Scam, also known as impersonation or fraud calls, which caused a loss of RM199.8 million, whereas e-commerce crimes accounted for 5,397 cases and a loss of RM71.6 million.

Furthermore, e-financial fraud or phishing has racked up as many as 543 cases, resulting in a loss of RM40.5 million [62]. Additionally, e-government, e-health, online shopping, and online banking have gradually changed into e-services which have been stated by Yesuf and Probst [8] throughout domains and industries as a means of optimising processes and facilitating engagement with both established and cutting-edge services of organisations. They also agreed [8] that the new systems and related services contain vulnerabilities that fraudsters might exploit to cause billions of dollars in losses to the global economy. In addition, [8] also mentioned the e-services platform developed for users' convenience has become insecure in recent years.

Fraud involving a cyber-aspect has shown a marked rising tendency, but traditional fraud has only declined a little. This pattern is expected to persist as more online transactions and banking are conducted. This tendency has made individuals fearful of online transactions, but not everyone takes action or realises the severity of the consequences when they become victims. According to a previous study by Button et al. [9], [10], being a victim of cyber fraud has negative consequences, such as psychological impact, financial losses, theft of intellectual property, invasion of privacy, and a loss of confidence and trust. Therefore, it is imperative to reduce the likelihood of becoming a target of fraudulent activities.

Next, Section II will provide a review of the relevant literature. Section III will discuss the methodology that has been employed, followed by Section IV, which presents the analysis and results. In Section V, the paper will deliberate on the research findings and acknowledge the study's constraints. Finally, Section VI will offer a conclusion, including recommendations for potential future research.

## II. RELATED WORK

### A. Underpinnings Theory

According to previous studies, there has been some investigation into the association between individual safety and protection motivation behaviour. Such as Anderson and Agarwal [11] discussed factors of computer safety, Li et al. [12] investigate factors of cybersecurity behaviour, Belanger et al. [13] explore factors in information security, Boss et al. [14] examine factors that motivate protective security behaviour, Chen et al. [15] discuss online scams and protection behaviour, Haag et al. [16] discuss protection motivation in information and lastly, Martens et al. [17] comparing factors intention of taking security measure against cybercrime. Protective behaviour is crucial for combating cyber threats, as people frequently experience connectivity issues when establishing connections between their devices and internet-based systems. Furthermore, Liang and Xue [18] stated that it plays a vital role in ensuring the safety of those who use the internet via various electronic devices in their daily lives. Multiple theories, including the theory of planned behaviour (TPB), rational choice theory (RCT), general deterrence theory (GDT), technology threat avoidance theory (TTAT), routine activity (RAT), and protection motivation theory (PMT), have been employed by information security researchers. For instance, Fansher and Randa used (RAT) [19], Kirwan et al.,[20] also used RAT, Rogers and Prentice-Dunn used PMT [21], Chen and Liang used TTAT [22], Tan et al. [23] used TPB, and last but not least Martens et al. [17] also using PMT to explain the reasons behind people's protective behaviours and intentions. These hypotheses are grounded in various disciplines, including computer science, criminology, business, and psychology. The cybersecurity issue has also been addressed by integrating and adapting the system to the current environment.

However, despite all the theories, this study discusses PMT, one of the most commonly used to examine protection behaviour. For instance, Haag et al. [16] use PMT to investigate information security, Martens et al. [17] use PMT for comparing scams, malware and cybercrime in general, Mohammed et al. [24] use PMT to identify dimension of protection behaviour, Warketin et al. [25] use PMT to explore protective behaviour, Jansen and Schaik [26] use PMT to study on phishing, and last but not least De Kimpe et al. [27], use PMT in cybercrime context. As protection behaviour is crucial in the digital world nowadays, a problem may arise if one does not know how to protect oneself when connecting with this digital world. Few studies also contend that it is unclear regarding the decision-making process individuals undergo when determining whether or not to take measures to safeguard themselves against cybercrime [27], [28]. Meanwhile, another study by Warkentin et al. [25] stated that PMT also plays a vital role in developing communication techniques that encourage individuals to take precautions against cyber threats. Thus, it is necessary to investigate what factors influence individual intentions regarding protection behaviour.

### B. PMT in Comparison with Past Studies

PMT consists of two appraisals, which are threat and coping. In PMT, threat appraisal was initially defined as a cognitive process by which an individual assesses a specific threat and the risk it poses [17]. It consists of two factors [17]: perceived severity and vulnerability. Perceived severity is the extent to which individuals perceive that the implications of a risk would be harmful, which increases their desire to take precautions [28]. Studies such as Dang-Pham and Pittayachawan [29], Losonczi [30], and Jansen et al. [31] have supported this statement.

Meanwhile, perceived vulnerability refers to the likelihood of being victimised by a particular threat. A previous study by Li et al. [32] found that users' ability to perceive the risk of a cyber-attack incident and identify effective preventive measures was insufficient, which subsequently affected their protective behaviour. This outcome holds notable significance. Another study by Thompson et al. [33] also had significant results where a user thought they were expected to have security risks and implied protection behaviours in their computing. Many studies such as Haag et al. [16], [24], [34] indicate that this construct plays an important role and is also one of the direct indicators that influence the motives for protection studies.

Besides, maladaptive rewards are also of crucial part of intention protection behaviour [35]. Maladaptive rewards mean users can save time or money by ignoring secure information management best practices [14], [21]. However, previous research such as Hassandoust et al. [35], Fisher-Prebler et al. [36], Chenoweth et al. [37] and Bax et al. [38] have not addressed how maladaptive rewards affect intention protection behaviours Furthermore, although PMT has been used to investigate several aspects of information security, researchers have focused on information security challenges in organisational contexts rather than specific ones. In addition, prior studies [18], [39] employing PMT to explore individuals' information security protective behaviours have yielded contradictory findings about the significance of the protection motivation mechanism. Therefore, this study aims to examine if maladaptive rewards affect the intended protection behaviour of e-services users.

As previously indicated, threat appraisal and maladaptive rewards have been discovered to influence protection. However, there is a lack of clarity on the antecedent elements that influence threat appraisal and maladaptive rewards. This issue has come to the attention of [16], who pointed out that most PMT research has concentrated on coping strategies and threat evaluation rather than antecedent variables. Additionally, as time progresses and technology keeps improving, it may become vital to investigate the antecedents to discover knowledge-enhancing insights. Therefore, this study proposes three antecedents for threat appraisal: (i) source credibility, (ii) perceived value of data, and (iii) wishful thinking, which will be explained next.

First, it is crucial to identify the origins of information since this can be an essential aspect of user protection and the initial step in determining the following action or behaviour. People are rationally more likely to defend themselves when

the source is unknown, and vice versa when the source's credibility can be verified. This study will investigate email source credibility in terms of where information comes from, as it has been recently highlighted as an unstudied issue in cybersecurity [16], [40].

Secondly, to analyse how they respond to a threat, it is necessary to comprehend their perception of data's value. Individuals possessing substantial wealth demonstrate a heightened awareness of security risks and are proactive in implementing preventive measures to mitigate such threats [41], [42]. Several past studies by [42], [43], have highlighted the perceived value of data from personal devices, which has a significant effect on intention protection. Considering that Western and Eastern societies have different levels of cultural and economic development, there is a pressing need for additional research in the context of Malaysia's growth.

Additionally, this study will investigate wishful thinking (WT) as an antecedent, which identifies beliefs as a factor that can influence maladaptive rewards. Wishful thinking is defined as an individual's "wish" that the IT threat would go away by itself without taking action [22], [44]. As a result, people become less concerned about information accuracy or objective probabilities [22]. For example, when users' wishful thinking is high, they will think that cyber threats do not severely impact them and will go away without action. As maladaptive rewards are about avoiding any safety or prevention measures to protect the individual from threats, this wishful thinking will significantly result in maladaptive rewards.

The previous paragraphs outlined the antecedents of threat appraisal and maladaptive rewards that will be investigated in this research. Alongside this, the appraisal of coping constructs will be examined. A coping appraisal is defined as the process by which an individual examines numerous protective techniques and avoids the threat [17]. Initially, PMT includes an individual's self-efficacy (the personal ability to implement a protection method), response efficacy (the effectiveness of approaches), and response cost (the concern about the potential expense associated with performing a recommended protective response) as the original constructs of the coping appraisal [16], [17], [26], [45]. These constructs influence a person's coping mechanisms towards cyber fraud. However, several studies have neglected to operationalize response costs due to their intricate and uncertain nature, as highlighted by [25], [46]. Moreover, current research indicates that self-efficacy has diminished explanatory power, resulting in a lack of significance and an inverse relationship [17], [29], [47], [48]. Therefore, this study only includes response efficacy as the coping appraisal.

## III. METHODOLOGY

### A. Instrument Development

The instrument is essential because it lets individuals know how well a study was done. If the criteria for the instrument are good, then the quality of the research is also good. If the criteria are flawed, then the quality of the research will be questionable. As the instrument turns fact into data, using a good one that is valid, reliable, and has a good level of difficulty will get data that reflects the facts or actual environments in the field [49]. However, a poor instrument will cause poor results in the study. In that case, the information gathered is also wrong or does not match the field's facts, leading to the wrong conclusion. Consequently, the development of instruments, as stated by Sekaran and Bougie [50] is an essential component of any research project and part of the research procedure.

This study aims to develop a data collection instrument that can be used to evaluate a proposed model and analyse the influence of relevant factors on the intention to protect behaviour. To create the instrument, the variables of the suggested model are operationalized within the context of the study. The instrument is used to gather empirical evidence to test the proposed framework as shown in Table I and Fig. 1.

TABLE I.        DEFINITION OF CONSTRUCT

| Construct | Definition | Source |
|---|---|---|
| Sources credibility | The information that a user receives from a person, authority, or source that they assume to be a reliable source of information | [38], [45] |
| Perceived value data | The emotional and monetary values of a user's data that are stored in e-services applications are referred to as perceived value data. | [29] |
| Wishful thinking | A person "wishes" that an information technology threat will disappear without requiring any action from him or her | [22], [44] |
| Perceived threat severity | The degree to which he or she recognises the presence of cyber fraud elements that represent a significant risk to him or her. The circumstance may prompt the user to take protective action. | [51], [52] |
| Perceived threat vulnerability | Relates to a user's perception of information security risks | [26] |
| Maladaptive Rewards | Refer to a circumstance in which a user feels he or she will receive additional benefits without adopting precautions. | [14], [29], [53] |
| Response efficacy | Relates to a user's reliance on the effectiveness of a cybersecurity suggestion | [54] |
| Intention protection behaviour | A term used to describe a user's instinct to protect themselves from an apparent danger | [14] |

After that, the researchers extract the original measurements used in past literature across several different fields and turn them into items. Due to that, the reliability of the instrument can be established [55]. Nevertheless, to increase the validity of the instrument, content validity testing needs to be carried out by experts.

### B. Content Validity

Content validity determines and assesses the degree to which the dimensions and components of a concept can be accurately and effectively defined [50]. An additional purpose of content validity is to ascertain the validity of each instrument item that corresponds to the measured construct [56]. Construct validity offers evidence or information to demonstrate that the items in a scale are interrelated and accurately measure the intended construct [49]. The greater the amount of content validity evidence gathered, including expert evaluation, the greater the researcher's confidence in

the constructed instruments' validity [57]. The panel of specialists can be classified into two groups, namely, professional experts and field experts [58].

Thus, before the process of determining the content validity of this study began, four expert panels were employed to evaluate the items and ensure the content validity of the instrument. A small discussion with four field experts regarding the item was conducted. This is to ensure the construct is well organised and the item represents the dimensions' possible measures. The clarity and relevance of the item have also been analysed. The four panels of professional university experts involved two senior lecturers and two associate professors.
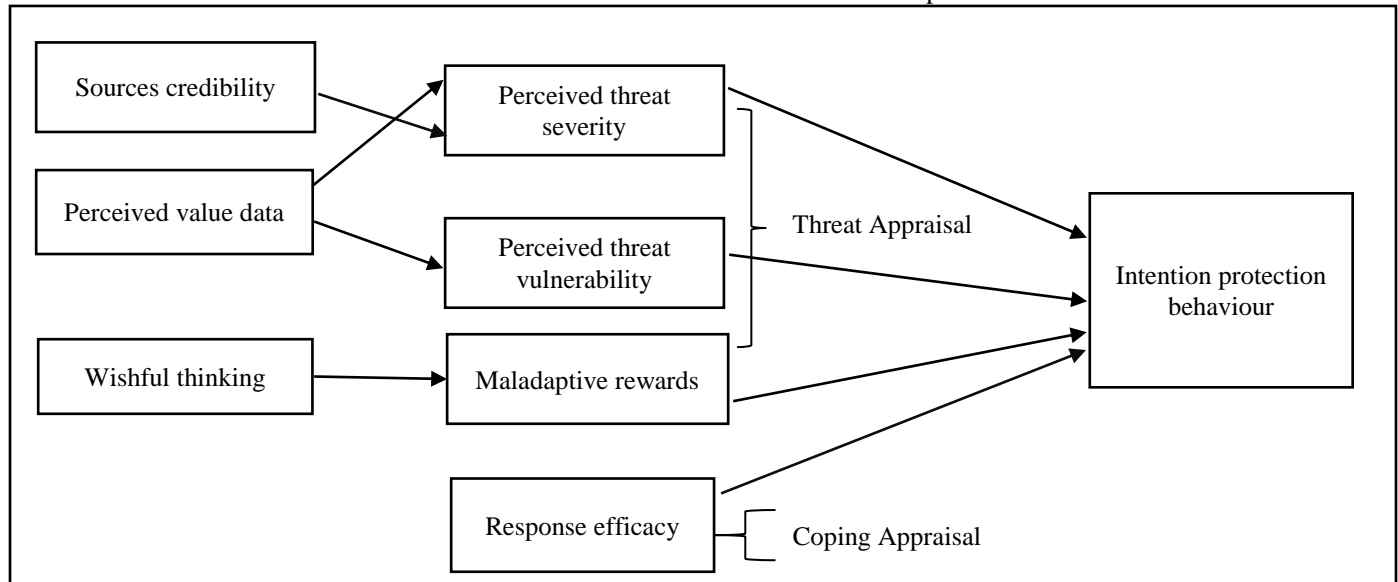


Fig. 1.   This study aims to develop.

In order to make the evaluation of the content validity easier, a form was designed to allow the experts to evaluate the relevance and clarity of the measurements. The form was designed by assigning a number (1, 2, or 3); 1 means the item is a Poor Match (remove item), 2 means a Modest Match (maintain item but needs some refining), and 3 means a Perfect Match (maintain the item as it is) so that the experts can evaluate the relevance and clarity of each item as shown in Table III.

## IV.   ANALYSIS AND RESULT

### A.  *Validity Analysis*

An analysis was conducted on the relevance and clarity assessments made by the experts for each item of the construct. CVI contains two components: Item-level CVI (I-CVI), which pertains to the content validity of individual items, and Scale-level CVI (S-CVI) evaluates the content validity of the entire scale [59]. The calculation of I-CVI involves dividing the number of experts who deemed the item relevant by the total number of experts who provided ratings. There are two techniques to calculate the S-CVI. One is known as S-CVI/UA and requires approval from all the experts. It is the proportion of elements on an instrument for which all experts acknowledge they are relevant. The other method is calculating the average I-CVI over all of the items, referred to as the S-CVI/Ave. The CVI for the current study instrument was determined, considering the relevance and clarity of each item. An overview of the CVI indices and a summary of the number agreement among experts may be found in Table II.

TABLE II.      CONTENT VALIDITY OF INDIVIDUAL ITEMS (I-CVI)

| Construct | Item No. | Summarize of No. Agreement | | I-CVI | |
|---|---|---|---|---|---|
| | | R | C | R | C |
| Source credibility | 1 | 3 | 3 | 1 | 1 |
| | 2 | 2 | 2 | 0.5 | 0.5 |
| | 3 | 3 | 3 | 1 | 1 |
| Perceived value data | 1 | 3 | 3 | 1 | 1 |
| | 2 | 3 | 3 | 1 | 1 |
| | 3 | 3 | 3 | 1 | 1 |
| Wishful thinking | 1 | 3 | 3 | 1 | 1 |
| | 2 | 3 | 3 | 1 | 1 |
| | 3 | 3 | 3 | 1 | 1 |
| Perceived threat severity | 1 | 3 | 3 | 1 | 1 |
| | 2 | 3 | 3 | 1 | 1 |
| | 3 | 3 | 3 | 1 | 1 |
| | 4 | 3 | 3 | 1 | 1 |
| Perceived threat vulnerability | 1 | 3 | 3 | 1 | 1 |
| | 2 | 3 | 3 | 1 | 1 |
| | 3 | 3 | 3 | 1 | 1 |
| Maladaptive rewards | 1 | 3 | 3 | 1 | 1 |
| | 2 | 3 | 3 | 1 | 1 |
| | 3 | 3 | 3 | 1 | 1 |

| | | | | | |
|---|---|---|---|---|---|
| | 4 | 3 | 3 | 1 | 1 |
| | 5 | 3 | 3 | 1 | 1 |
| Response efficacy | 1 | 3 | 3 | 1 | 1 |
| | 2 | 3 | 3 | 1 | 1 |
| | 3 | 3 | 3 | 1 | 1 |
| Intention protection motivation | 1 | 3 | 3 | 1 | 1 |
| | 2 | 3 | 3 | 1 | 1 |
| | 3 | 3 | 3 | 1 | 1 |
| | 4 | 3 | 3 | 1 | 1 |
| | 5 | 3 | 3 | 1 | 1 |
| R= Relevance C=Clarity | | | | | |

The results demonstrate that the I-CVI for one question does not meet the criteria for item acceptability recommended by [59], [60], which states that it must be 1 for 3-5 experts to be considered acceptable. This pertains to the relevance of the items. According to the S-CVI figures, SCVI/UA and S-CVI/Ave are 0.97 and 0.98, respectively (see Table III). The

lowest value of acceptability for S-CVI as determined by [61] is 0.80, and these results are significantly higher than that limit.

Besides that, the results of calculating the I-CVI for the clarity of the items suggest that one of the items is not clear enough (0.5) (see Table II). The experts gave their feedback to help make the items more comprehensible. In addition, the S-CVI/UA and S-CVI/Ave ratios for the items' clarity reveal satisfactory levels with corresponding values of 0.97 and 0.98. (See Table III).

TABLE III.     SCALE-LEVEL CONTENT VALIDITY INDEX (S-CVI)

| | **Relevance** | **Clarity** |
|---|---|---|
| S-CVI/Ave | 0.98 | 0.98 |
| Total agreement | 28/29 | 28/29 |
| S-CVI/UA | 0.97 | 0.97 |

Hence, the instrument was amended in line with the expert's feedback. Table IV indicates the updated scale measurements.

TABLE IV.     UPDATED MEASUREMENTS

| Constructs | Original | Revised |
|---|---|---|
| Source credibility | I believe emails from the Malaysian government domain (.gov) are credible. | I believe emails from all e-Services domains (.gov.my; .edu.my; .com.my) are credible. |
| | I believe emails from the Malaysian government domain (.gov) tend to be free from grammatical errors. | I believe emails from all e-Services domains (.gov.my; .edu.my; .com.my) tend to be free from grammatical errors. |
| | I believe emails from the Malaysian government domain (.gov) tend to have a sense of urgency. | I believe emails from all e-Services domains (.gov.my; .edu.my; .com.my) tend to have a sense of urgency. |
| Perceived value data | I perceive the importance of regarding the security protection of my data in e-services. | I perceived the importance of security protection towards my data in e-Services |
| | I am aware of the potential risk of monetary loss if there are breaches of my personal data**.** | I am aware of the potential risk of monetary loss if there are breaches of my personal data. |
| | I perceived the e-services highly guarantee the confidentiality of my personal data. | I perceived the e-services could fully guarantee the confidentiality of my personal data |
| Wishful thinking | I wish I could use e-services without increasing my security protection. | I wish I could use e-Services without increasing my security protection. |
| | I wish that the threat would go away or somehow not affect me. | I wish that the threat would go away by itself. |
| | | I wish that the threat would not affect me. |
| | I hope I will not encounter any cyber threat situations. | I hope I will not encounter any cyber threat situations. |
| Perceived threat severity | I believe that being a victim of cyber fraud in e-services is a serious problem for me. | I believe that being a victim of cyber fraud in e-services is a serious problem for me. |
| | I believe that the time/masa loss to recover the damages (e.g., money loss, data loss) after being a victim of cyber fraud is a serious problem. | I believe that the time lost to recover the damages after being a victim of cyber fraud is a serious problem. |
| | I believe that my productivity/effort loss to recover the damages (e.g., loss of income) from being a victim of cyber fraud is a serious problem. | I believe that my productivity/effort loss (e.g., loss of income) to recover the damages from being a victim of cyber fraud is a serious problem. |
| | I believe that the data/information loss from being a victim of cyber fraud is a serious problem. | I believe that the data/information loss from being a victim of cyber fraud is a serious problem. |
| Perceived threat vulnerability | I am exposed to the cyber fraud threats of e-services. | I am exposed to the cyber fraud threats of e-Services. |
| | I am at risk of being victimised by cyber fraud attackers. | I am at risk of being victimized by cyber fraud attacker |
| | I will likely become a victim of cyber fraud. | I can become a victim of cyber fraud |
| Maladaptive rewards | I can save my time if I'm not using any preventive countermeasures application (e.g.: antivirus, anti-malware). | I can save my time if I am not using any preventive countermeasures application (e.g.: antivirus, anti-malware). |
| | I can save my money if I'm not using any preventive countermeasure applications. | I can save my money if I am not using any preventive countermeasure applications. |
| | I will be better informed of the security risk if I'm using | I think it is a waste of effort to spend more money on |

| | | |
|---|---|---|
| | any preventive countermeasure applications. | anti-virus software to increase the protection against cyber fraud |
| | I will spend less effort if I do not perform the recommendations of the preventive countermeasure applications. | I will spend less effort if I do not perform the recommendations of the preventive countermeasure applications. |
| | I will feel less stressful if I do not perform the recommendations of the preventive countermeasure applications. | I will feel less stressful if I do not perform the recommendations of the preventive countermeasure applications. |
| Response efficacy | When using a preventive countermeasures application, a computer's data is more likely to be protected. | When using preventive countermeasures applications, computer data is more likely to be protected. |
| | Performing any cybersecurity recommendations would reduce the chance of myself from becoming a cyber fraud victim. | Performing any cybersecurity recommendation would reduce the chance of me from becoming a cyber fraud victim. |
| | Performing any of the provided recommendations make me feel safe from cyber fraud attack. | Performing any of the provided recommendations makes me feel safe from a cyber fraud attack |
| Intention protection Motivation | I will update my knowledge to use e-services safely. | I will update my knowledge to use e-Services safely. |
| | I will likely engage in activities that protect my personal information from cyber fraud when I use e-services. | I will likely engage in activities that protect my personal information from cyber fraud when I use e-services. |
| | I intend to protect myself from cyber fraud when I use e-services. | I intend to protect myself from cyber fraud when I use e-Services. |
| | I am willing to spend more in order to protect myself from cyber fraud when I use e-services. | I am willing to spend more money in order to protect myself from cyber fraud when I use e-Services |
| | I will likely take precaution that protects my personal information from cyber fraud when I use e-services. | I will likely take precaution that protects my personal information from cyber fraud when I use e-Services. |

## V. DISCUSSION

Using the PMT point of view, through this instrument development, this study aims to investigate the factors of human behaviour that can lead to the intention to protect oneself from becoming a victim of cyber fraud while participating in online activities. In the first part of this research study, an investigation into the influence of threat appraisal on the intention protection behaviour of the user when utilising e-services will be carried out. In addition, maladaptive rewards will also be investigated, [14], [16], [37], [38] as there have been numerous debates over this issue in past studies.

Practically, the results of this study will be beneficial to individuals in the sense that they will gain an understanding of the kinds of factors that can make them susceptible to fraudsters and the kinds of responses they should make when confronted with a situation in which they are at risk of being victims of cyber fraud. Before becoming the next victim of cyber fraud, consumers must recognise how their habits can either help or threaten them. With these characteristics, enhanced protection can be created, preventing consumers from falling prey to fraudsters. In addition, these studies will have made significant contributions to the development of PMT-based information security research. It will investigate new antecedent factors incorporated into PMT as new components.

In addition, this research creates a tool for measuring the model's constructs. The items for each construct were drawn from relevant theories and literature and then revised to reflect the topic of the study. The validity of the measurement may be compromised by adapting the original items to the context of the study. Therefore, content validation was done to verify that the items adequately reflected the subject domain. Initial evidence of construct validity is provided by content validity. In addition, it gives indicators of the items' representativeness and clarity and contributes to the enhancement of the instrument by considering the suggestions of experts [62].

In the current study, four experts evaluated the items' relevance and clarity. The results indicated that 28 items were accepted, except one item was not considerably clear (in terms of wording); hence, the item was graded as "keep it but refine it to the corresponding construct". These elements were updated in response to the feedback of the experts. All item and construct comments were considered in the amended version of the instrument. These components were extracted from the relevant literature, considering the cyber fraud environment's setting.

Lastly, despite the careful expert selection, the study can be enhanced by involving a more diverse range of experts for additional insights and improvements.

## VI. CONCLUSION

To summarise, the findings of this study can provide a new instrument construct base for future studies. All 29 items will be subjected to a pilot testing phase by administering the questionnaire to the designated participants. Subsequently, this pilot study will entail subjecting the items to further rigorous statistical analyses aimed at substantiating their reliability and validity for inclusion in the primary research investigation.

Academically, this study would benefit the body of knowledge, including institutions, colleges, and universities, because it can provide new knowledge for academics who intend to publish it in an open-access journal or send it to a publisher. The entire variable will be examined, and the results might be used to increase the output of research on this subject in Malaysia, specifically for academic institutions. In addition, it enables academicians to create substantial countermeasures against cyber fraud in Malaysia.

Besides that, in order to enhance the explanatory capacity of the model, it may be expedient to incorporate supplementary variables to expand the framework. This could involve broadening the scope of constructs beyond those pertaining to source credibility, maladaptive rewards, wishful thinking, perceived vulnerability, perceived severity, and

response efficacy. Lastly, a greater understanding of this kind of behaviour will aid professionals in designing, developing, and executing new methods or enhancements for e-service users. This study was conducted in support of a government aiming to develop and maintain a safer cyberspace to achieve national sustainability, social well-being, and wealth creation. Perhaps this research will aid in reducing the losses incurred by the government as a consequence of cyber fraud.

REFERENCES

[1] Bendovschi, "Cyber-Attacks – Trends, Patterns and Security Countermeasures," Procedia Economics and Finance, vol. 28, no. January, pp. 24–31, 2015, doi: 10.1016/s2212-5671(15)01077-1.

[2] B. Bulgurcu, H. Cavusoglu, and I. Benbasat, "Information Security Policy Compliance: An Empirical Study of Rationality-Based Beliefs and Information Security Awareness," MIS Quarterly, vol. 34, no. 3, pp. 523–548, Sep. 2010, doi: 10.2307/25750690.

[3] N. H. S. Khalifa Sultan Khalifa Humaid; Al-kumaim, "A conceptual model for prevention of e-financial crimes in UAE: a review paper," Academic of Strategic Management Journal, vol. 20, no. Special Issue 6, pp. 1–11, 2021.

[4] D. Kuru and S. Bayraktar, "The effect of cyber-risk insurance to social welfare," J Financ Crime, vol. 24, no. 2, pp. 329–346, 2017, doi: 10.1108/JFC-05-2016-0035/FULL/PDF.

[5] S. Ye and K. K. W. Ho, "Would you feel happier if you have more protection behaviour? A panel survey of university students in Japan," Behaviour and Information Technology, vol. 38, no. 4, pp. 422–434, 2019, doi: 10.1080/0144929X.2018.1544275.

[6] T. Sorell and M. Whitty, "Online romance scams and victimhood," Security Journal, no. 0123456789, 2019, doi: 10.1057/s41284-019-00166-w.

[7] T. Kvasnicova, I. Kremenova, J. Fabus, and B. Babusiak, "E-commerce user experience: Do we feel under pressure during online shopping?," in WMSCI 2016 - 20th World Multi-Conference on Systemics, Cybernetics and Informatics, Proceedings, 2016.

[8] A. S. Yesuf and C. W. Probst, "Estimating the Risk of Fraud Against E-Services," in Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics), 2018. doi: 10.1007/978-3-030-03638-6_19.

[9] M. Button, C. M. N. Nicholls, J. Kerr, and R. Owen, "Online frauds: Learning from victims why they fall for these scams," Australian and New Zealand Journal of Criminology, vol. 47, no. 3, pp. 391–408, 2014, doi: 10.1177/0004865814521224.

[10] D. H. Shih, B. Lin, H. Sen Chiang, and M. H. Shih, "Security aspects of mobile phone virus: A critical survey," Industrial Management and Data Systems, vol. 108, no. 4, pp. 478–494, 2008, doi: 10.1108/02635570810868344/FULL/PDF.

[11] C. L. Anderson and R. Agarwal, "Practicing safe computing: A multimethod empirical examination of home computer user security behavioral intentions," MIS Q, 2010, doi: 10.2307/25750694.

[12] L. Li, W. He, L. Xu, I. Ash, M. Anwar, and X. Yuan, "Investigating the impact of cybersecurity policy awareness on employees' cybersecurity behavior," Int J Inf Manage, vol. 45, pp. 13–24, Apr. 2019, doi: 10.1016/j.ijinfomgt.2018.10.017.

[13] R. Crossler and F. Bélanger, "An extended perspective on individual security behaviors: Protection motivation theory and a unified security practices (USP) instrument," Data Base for Advances in Information Systems, 2014, doi: 10.1145/2691517.2691521.

[14] S. R. Boss, D. F. Galletta, P. B. Lowry, G. D. Moody, and P. Polak, "What do systems users have to fear? Using fear appeals to engender threats and fear that motivate protective security behaviors," MIS Q, 2015, doi: 10.25300/MISQ/2015/39.4.5.

[15] H. Chen, C. E. Beaudoin, and T. Hong, "Securing online privacy: An empirical test on Internet scam victimization, online privacy concerns, and privacy protection behaviors," Comput Human Behav, 2017, doi: 10.1016/j.chb.2017.01.003.

[16] S. Haag, M. Siponen, and F. Liu, "Protection Motivation Theory in Information Systems Security Research: A Review of the Past and a Road Map for the Future," Data Base for Advances in Information Systems, vol. 52, no. 2, pp. 25–67, May 2021, doi: 10.1145/3462766.3462770.

[17] M. Martens, R. De Wolf, and L. De Marez, "Investigating and comparing the predictors of the intention towards taking security measures against malware, scams and cybercrime in general," Comput Human Behav, vol. 92, no. May 2018, pp. 139–150, 2019, doi: 10.1016/j.chb.2018.11.002.

[18] H. Liang and Y. Xue, "Understanding security behaviors in personal computer usage: A threat avoidance perspective," J Assoc Inf Syst, 2010, doi: 10.17705/1jais.00232.

[19] A. K. Fansher and R. Randa, "Risky Social Media Behaviors and the Potential for Victimization: A Descriptive Look at College Students Victimized by Someone Met Online," Violence Gend, vol. 6, no. 2, pp. 115–123, 2019, doi: 10.1089/vio.2017.0073.

[20] G. H. Kirwan, C. Fullwood, and B. Rooney, "Risk Factors for Social Networking Site Scam Victimization among Malaysian Students," Cyberpsychol Behav Soc Netw, vol. 21, no. 2, pp. 123–128, 2018, doi: 10.1089/cyber.2016.0714.

[21] R. W. Rogers and S. Prentice-Dunn, "Protection Motivation Theory," in Handbook of health behavior research 1: Personal and social determinants, 1997, pp. 113–132. doi: 10.4135/9781483332222.n225.

[22] D. Q. Chen and H. Liang, "Wishful Thinking and IT Threat Avoidance: An Extension to the Technology Threat Avoidance Theory," IEEE Trans Eng Manag, 2019, doi: 10.1109/TEM.2018.2835461.

[23] K.-L. Tan, Y. Liu, and Q. Ye, "A gendered discourse on truthful disclosure of financial fraud practices among accountants in China: implications to corporate governance," Accounting Research Journal, vol. 36, no. 2/3, pp. 230–250, Jan. 2023, doi: 10.1108/ARJ-07-2022-0160.

[24] I. Mohammed Al-harthy, F. Abdul Rahim, A. Ali, and A. P. Singun Jr, "Dimensions of protection behaviors: A systematic literature review," J Theor Appl Inf Technol, vol. 15, p. 17, 2020, [Online]. Available: www.jatit.org

[25] M. Warkentin, A. C. Johnston, J. Shropshire, and W. D. Barnett, "Continuance of protective security behavior: A longitudinal study," Decis Support Syst, vol. 92, no. May 2018, pp. 25–35, 2016, doi: 10.1016/j.dss.2016.09.013.

[26] J. Jansen and P. van Schaik, "Persuading end users to act cautiously online: a fear appeals study on phishing," Information and Computer Security, vol. 26, no. 3, pp. 264–276, 2018, doi: 10.1108/ICS-03-2018-0038.

[27] L. De Kimpe, M. Walrave, P. Verdegem, and K. Ponnet, "What we think we know about cybersecurity: an investigation of the relationship between perceived knowledge, internet trust, and protection motivation in a cybercrime context," Behaviour and Information Technology, vol. 0, no. 0, pp. 1–13, 2021, doi: 10.1080/0144929X.2021.1905066.

[28] B. W. Reyns, R. Randa, and B. Henson, "Preventing crime online: Identifying determinants of online preventive behaviors using structural equation modeling and canonical correlation analysis," Crime Prevention and Community Safety, vol. 18, no. 1, pp. 38–59, 2016, doi: 10.1057/cpcs.2015.21.

[29] D. Dang-Pham and S. Pittayachawan, "Comparing intention to avoid malware across contexts in a BYOD-enabled Australian university: A Protection Motivation Theory approach," Comput Secur, vol. 48, pp. 281–297, 2015, doi: 10.1016/j.cose.2014.11.002.

[30] P. Lošonczi, "Importance of Dealing with Cybersecurity Challenges and Cybercrime in the Senior Population," Security Dimensions, vol. 26, no. 26, pp. 173–186, 2018, doi: 10.5604/01.3001.0012.7249.

[31] J. Jansen and P. van Schaik, "The design and evaluation of a theory-based intervention to promote security behaviour against phishing," Int J

Hum Comput Stud, vol. 123, pp. 40–55, Mar. 2019, doi: 10.1016/j.ijhcs.2018.10.004.

[32] L. Li, W. He, L. Xu, I. Ash, M. Anwar, and X. Yuan, "Investigating the impact of cybersecurity policy awareness on employees' cybersecurity behavior," Int J Inf Manage, vol. 45, pp. 13–24, 2019, doi: 10.1016/j.ijinfomgt.2018.10.017.

[33] N. Thompson, T. J. McGill, and X. Wang, "'Security begins at home': Determinants of home computer and mobile device security behavior," Comput Secur, 2017, doi: 10.1016/j.cose.2017.07.003.

[34] M. Grimes and J. Marquardson, "Quality matters: Evoking subjective norms and coping appraisals by system design to increase security intentions," Decis Support Syst, vol. 119, no. February, pp. 23–34, 2019, doi: 10.1016/j.dss.2019.02.010.

[35] F. Hassandoust and A. A. Techatassanasoontorn, "Understanding users' information security awareness and intentions: A full nomology of protection motivation theory," Proceedings of the 22nd Pacific Asia Conference on Information Systems - Opportunities and Challenges for the Digitized Society: Are We Ready?, PACIS 2018, 2018.

[36] D. Fischer-Preßler, D. Bonaretti, and K. Fischbach, "A Protection-Motivation Perspective to Explain Intention to Use and Continue to Use Mobile Warning Systems," Business and Information Systems Engineering, vol. 64, no. 2, pp. 167–182, Apr. 2022, doi: 10.1007/S12599-021-00704-0/TABLES/3.

[37] T. Chenoweth, T. Gattiker, and K. Corral, "Adaptive and Maladaptive Coping with an It Threat," https://doi.org/10.1080/10580530.2018.1553647, vol. 36, no. 1, pp. 24–39, Jan. 2019, doi: 10.1080/10580530.2018.1553647.

[38] S. Bax, T. McGill, and V. Hobbs, "Maladaptive behaviour in response to email phishing threats: The roles of rewards and response costs," Comput Secur, vol. 106, p. 102278, 2021, doi: 10.1016/j.cose.2021.102278.

[39] B. Hanus and Y. "Andy" Wu, "Impact of Users' Security Awareness on Desktop Security Behavior: A Protection Motivation Theory Perspective," Information Systems Management, 2016, doi: 10.1080/10580530.2015.1117842.

[40] A. Appelman and S. S. Sundar, "Measuring Message Credibility: Construction and Validation of an Exclusive Scale," http://dx.doi.org/10.1177/1077699015606057, vol. 93, no. 1, pp. 59–79, Oct. 2015, doi: 10.1177/1077699015606057.

[41] S. Chai, S. Bagchi-Sen, C. Morrell, H. R. Rao, and S. J. Upadhyaya, "Internet and online information privacy: An exploratory study of preteens and early teens," IEEE Trans Prof Commun, 2009, doi: 10.1109/TPC.2009.2017985.

[42] S. Srisawang, M. Thongmak, and A. Ngarmyarn, "Factors affecting computer crime protection behavior," in Pacific Asia Conference on Information Systems, PACIS 2015 - Proceedings, 2015.

[43] I. Mahmud, T. Ramayah, Md. M. H. Nayeem, S. M. M. M. Islam, and P. L. Gan, "Modelling Cyber-Crime Protection Behaviour among Computer Users in the Context of Bangladesh," in Design Solutions for User-Centric Information Systems, 2016. doi: 10.4018/978-1-7998-2466-4.ch021.

[44] S. Folkman, R. S. Lazarus, C. Dunkel-Schetter, A. DeLongis, and R. J. Gruen, "Dynamics of a Stressful Encounter. Cognitive Appraisal, Coping, and Encounter Outcomes," J Pers Soc Psychol, 1986, doi: 10.1037/0022-3514.50.5.992.

[45] S. Milne, S. Orbell, and P. Sheeran, "Combining motivational and volitional interventions to promote exercise participation: Protection motivation theory and implementation intentions," Br J Health Psychol, 2002, doi: 10.1348/135910702169420.

[46] M. O. Lwin, B. Li, and R. P. Ang, "Stop bugging me: An examination of adolescents' protection," J Adolesc, 2012.

[47] P. Menard, G. J. Bott, and R. E. Crossler, "User Motivations in Protecting Information Security: Protection Motivation Theory Versus Self-Determination Theory," Journal of Management Information Systems, vol. 34, no. 4, pp. 1203–1230, 2017, doi: 10.1080/07421222.2017.1394083.

[48] H. Y. S. Tsai, M. Jiang, S. Alhabash, R. Larose, N. J. Rifon, and S. R. Cotten, "Understanding online safety behaviors: A protection motivation theory perspective," Comput Secur, vol. 59, pp. 138–150, 2016, doi: 10.1016/j.cose.2016.02.009.

[49] N. Ghazali, M. S. Nordin, and T. B. Tunku Ahmad, "Development and Validation of Student's MOOC-efficacy Scale: Exploratory Factor Analysis," Asian Journal of University Education; Vol 17 No 4 (2021): AJUE Vol 17 No 4 October 2021DO - 10.24191/ajue.v17i4.16182 , Nov. 2021.

[50] U. Sekaran and R. Bougie, "Research Methods for Business 6th United Kingdom," 2014.

[51] J. E. Maddux and R. W. Rogers, "Protection motivation and self-efficacy: A revised theory of fear appeals and attitude change," J Exp Soc Psychol, 1983, doi: 10.1016/0022-1031(83)90023-9.

[52] K. Witte, "Putting the fear back into fear appeals: The extended parallel process model," Commun Monogr, vol. 59, no. 4, pp. 329–349, 1992, doi: 10.1080/03637759209376276.

[53] D. L. Floyd, S. Prentice-DFloyd, D. L., Prentice-Dunn, S., & Rogers, R. W. (2000). A meta-analysis of research on protection motivation theory. Journal of Applied Social Psychology. https://doi.org/10.1111/j.1559-1816.2000.tb02323.xunn, and R. W. Rogers, "A meta-analysis of research on protection motivation theory," J Appl Soc Psychol, 2000, doi: 10.1111/j.1559-1816.2000.tb02323.x.

[54] J. Ophoff and M. Lakay, "Mitigating the Ransomware Threat: A Protection Motivation Theory Approach," in Communications in Computer and Information Science, 2019. doi: 10.1007/978-3-030-11407-7_12.

[55] N. K. Agarwal, "Verifying survey items for Construct Validity: A two-stage Sorting Procedure for Questionnaire Design in Information Behavior Research," 2011. doi: https://asistdl.onlinelibrary.wiley.com/doi/full/10.1002/meet.2011.14504801166.

[56] L. A. Miller, R. L. Lovler, and S. A. McIntire, "Foundations of psychological testing : a practical approach," p. 624, 2013.

[57] Burke. Johnson and L. B. Christensen, "Educational research : quantitative, qualitative, and mixed approaches," p. 621, 2012.

[58] D. M. G. Rubio, M. Berg-Weger, S. S. Tebb, E. S. Lee, and S. Rauch, "Objectifying content validity: Conducting a content validity study in social work research," Soc Work Res, vol. 27, no. 2, pp. 94–104, Jun. 2003, doi: 10.1093/SWR/27.2.94.

[59] M. R. Lynn, "Determination and quantification of content validity," Nurs Res, vol. 35, no. 6, pp. 382–386, 1986, doi: 10.1097/00006199-198611000-00017.

[60] D. F. Polit, C. T. Beck, and S. V. Owen, "Is the CVI an acceptable indicator of content validity? Appraisal and recommendations," Res Nurs Health, vol. 30, no. 4, pp. 459–467, Aug. 2007, doi: 10.1002/NUR.20199.

[61] L. L. Davis, "Instrument review: Getting the most from a panel of experts," Applied Nursing Research, vol. 5, no. 4, pp. 194–197, Nov. 1992, doi: 10.1016/S0897-1897(05)80008-4.

[62] M. Saiful and B. Yusoff, "ABC of content validation and content validity index calculation," Malaysian Association of Education in Medicine and Health Sciences, vol. 11, no. 2, pp. 49–54, 2019, doi: 10.21315/eimj2019.11.2.6.

# A Model for Pervasive Computing and Wearable Devices for Sustainable Healthcare Applications

Deshinta Arrova Dewi[1], Rajermani Thinakan[2], Malathy Batumalay[3], Tri Basuki Kurniawan[4]

Faculty of Data Science and Information Technology-INTI International University, Nilai, Malaysia[1, 2, 3]
Faculty of Science and Technology-Bina Darma University, Palembang, Indonesia[4]
Faculty of Technology and Information Science-Universiti Kebangsaan Malaysia (UKM), Bangi, Malaysia[4]

*Abstract*—The user's demands in the system supported by the Internet of Things are frequently controlled effectively using the pervasive computing system. Pervasive computing is a term used to describe a system that integrates several communication and distributed network technologies. Even so, it properly accommodates user needs. It is quite difficult to be inventive in the pervasive computing system when it comes to the delivery of information, handling standards, and extending heterogeneous aid for scattered clients. In this view, our paper intends to utilize a Dispersed and Elastic Computing Model (DECM) to enable proper and reliable communication for people who are using IoT-based wearable healthcare devices. Recurrent Reinforcement Learning (RRL) is used in the suggested model and the system that is connected to analyze resource allocation in response to requirements and other allocative factors. To provide effective data transmission over wearable medical devices, the built system gives managing mobility additional consideration to resource allocation and distribution. The results show that the pervasive computing system provides services to the user with reduced latency and an increased rate of communication for healthcare wearable devices based on the determined demands of the resources. This is an important aspect of sustainable healthcare. We employ the assessment metrics consisting of request failure, response time, managed and backlogged requests, bandwidth, and storage to capture the consistency of the proposed model.

*Keywords—Internet of Things; wearable devices; pervasive computing; sustainable healthcare; healthcare applications; public health; health system*

## I. INTRODUCTION

The world has been modernized and changed into a pervasive computing system environment because of recent advancements in many applications that are capable of sensing and interacting everywhere. The devices that can work wirelessly and are enhanced with sensing, processing, and decision-making capabilities are integrated with real-world items to generate the correct service delivery for the Internet of Things. This kind of service is in high demand among businesses in the healthcare, IT, communication, and multimedia sectors. The needs of the user are met through rapid service delivery and improved "querying requests."

Integrating a wide range of devices, from sensors to intelligent machines, is necessary to access the network and all its resources. Consumers were granted unrestricted, global freedom to use resources anywhere in the world through increasing communication through the end users' devices. The device allowed a wide range of applications by connecting to the clients through external networks and services and employing adaptive conveyance mechanisms.

To provide pervasive services, it is crucial for users to concentrate on the service and receive reliable services that meet their needs. The ability to employ heterogeneous devices as a form of service is enabled by a pervasive computing environment. The services are delivered through networks that integrate the communication interface of various service systems and the fundamental systems to expand communication.

In a distributed system, pervasive computing has the authority to employ several computing paradigms to meet user expectations. It offers a variety of services, including simultaneous user access, service configuration, computer-related inquiries, resource allocation, and resource distribution. The data were scattered throughout numerous healthcare sectors, and the Internet of Things' flexible sensor network was used to combine a variety of sensors to facilitate data conveyance. The software-defined network (SDN), mobile networks, medical sensor data centers, distributed servers, and edge processing networks were all included to achieve a resilient service for edge users.

Extending trustworthy and adaptable communication is crucial but difficult and complex in the case of the large-scale pervasive computing environment. A novel dispersed and elastic computing model (DECM) has been created by previous researchers at [1] for the IoT-based wearable healthcare device in the pervasive computing environment. The developed system uses Recurrent Reinforcement Learning (RRL) to analyze how resources are distributed in accordance with demands and other allocative factors.

The pervasive computing system delivers services to the user in the end with a reduced amount of latency and an increased rate of communication for the medical wearable devices based on the calculated resource requirements. The designed system places additional attention on managing mobility in addition to resource distribution and distribution for proper data transmission over the wearable healthcare device.

By balancing the flow of requests across the network, the planned layout accelerates the processing of requests. The RRL is used in the request balancing process. As a result, the volume of requests handled increases while the response time decreases. By employing RRL to optimize the storage, the

bandwidth rate is increased. Additionally, this paper analyses the design empirically and compares the results to existing methods.

This paper is organized as follows. Section II explains related works done by the previous research. Section III discusses the computing model used in our study. Section IV highlights the results and discussion of our experiments. Section V is the conclusion and a brief of future works.

## II.   RELATED WORKS

Azariadi et al. [2] have suggested a method for deciphering the heartbeat from the ECG and further implemented the method to a wearable medical device that does continuous 24x7 monitoring. The review of WHCD is presented by Haghi et al. [3] in both academic publications and for-profit endeavors. The method was developed to get around the challenges in device data mapping and matching using the enhanced petri net service model, according to Lomotey, et al.'s [4] presentation of an IoT architecture for data streaming delivering traceability of data route from the originating source to the Health data center."

Al-Makhadmeh, et al. [5] use the deep learning method to learn from past analyses and predict the course of cardiac disease. Higher-order Boltzmann deep belief neural networks were used by the system. A "Systematic Review of Wearable Sensors and IoT-Based Monitoring Applications for Older Adults-a Focus on Ageing Population and Independent Living" is presented by Baig et al. in their paper [6].

Yang et al.'s [7] "introduced a new method for ECG monitoring based on IOT techniques, in which ECG data are gathered using the wearable monitoring node and are directly transferred to the IOT cloud using Wi-Fi. In the IOT cloud, both HTTP and MQTTP are utilized to provide consumers with timely and illustrative ECG data. The "Smart wearable system for safety-related medical IoT application: Case of epileptic patient working in an industrial environment" was carried out by Hayek, et al. [5]. The remote care-taking applications Silva, et al. [8] "designed could be implemented for patients. This system is used as a waist belt and shoe with embedded sensors.

The Compact Wearable Meta Materials Antennas for Energy Harvesting Systems, Medical, and IoT Systems are done by Sabban, Albert, et al. Dey, Nilanjan, and colleagues [9,10] described the difficulties and potential uses of implantable and wearable medical devices. The IoT-Based Noninvasive Wearable and Remote Intelligent Pervasive Healthcare Monitoring Systems for the Elderly People were presented by Balasubramaniam, et al. Greco, Luca, and colleagues in [11] presented Trends in IoT-based solutions for health care: moving AI to the Edge. Big Data Business Analytics as a Strategic Asset for the Health Care Industry was explored by Smys, S., et al. The Cloud based Internet of Things for smart connected objects"was presented by Duraipandian et al. The "Effective Fragmentation Minimization by Cloud Enabled Back up Storage" was carried out by Pandian, A. Pasumpon, et al. The Special Section on Innovative Engineering Solutions for Future Health Care Informatics" has been discussed by Joy Iong-Zong Chen et al. [12]. Recurrent Neural Networks and Nonlinear Prediction in Support Vector Machines were presented by Raj, Jennifer S. et al. [13].

These previous works have highlighted the need for more experiments, especially for people who are using IoT-based wearable healthcare devices or employ heterogeneous devices as a form of service.

Our study is narrower in scope and restricted to IoT devices utilized in healthcare, as opposed to earlier research. The figures are provided by a startup business that works on Internet of Things devices in one of Malaysia's cities, and they receive 600 inquiries on average. With our method, we aim to outperform the existing system while maintaining the same configuration environment.

## III.   COMPUTING MODEL FOR PERVASIVE COMPUTING: IoT HEALTHCARE

The pervasive computing's flexibility and elasticity are inherent qualities that enable the operation of heterogeneous devices and encourage interoperability. DECM is utilized to provide service help to many users at once. By computing the requests and optimizing the storage with RLL, the delivery rate of the service is increased.

The cloud, device, substructure, and ubiquitous layer are significant planes that make up the laid-out design. Numerous users and mobile IoT wearable devices that request resources from the cloud plane augment the ubiquitous layer. The aircraft accepts mixed-applications usage and conveyance methodologies that assess user requirements in accordance with information storage standards. Additionally prevalent on this level are computing and data analytics.

The proposed framework is presented in a block diagram in Fig. 1.

As in SDN, the device plane makes up the control plane and performs the crucial computation of requests and storage optimization to increase the communication rate. The substructure plane is equipped with access points, gateways, and BS that support heterogeneous communication by integrating a variety of data conveyance technologies based on Internet of Things-related sensor technology. The potential of the substructure plane to cover a wide geographic region and provide users with ubiquitous communication is what makes it significant. The information that has been gathered is stored on the cloud plane for later use. The committed cloud services handled the clients' requests for access to the information that was stored and oversaw computation and resource allocation. Even though the cloud offers authenticated customers the anytime, anywhere right to use, it still only functions as a third party.
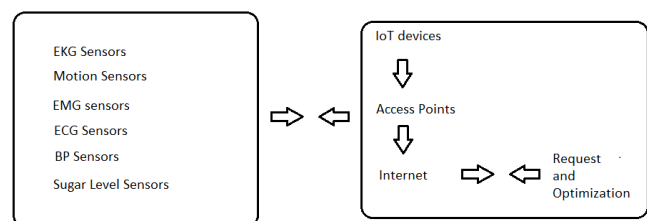


Fig. 1.   Proposed workflow.

The proposed system analyses the request and optimizes the storage using RRL to increase the rate of conveyance. Utilizing a personal device that uses Wi-Fi or Zig-Bee to upload the requests, the processing of the request enables one to organize the requests and transport them to the cloud plane.

This reduces the amount of time needed to process requests, eliminates blocking scenarios, and ensures a constant flow of data into the pervasive computing environment. Eq. (1) provides an approximation of the request processing rate.

$$Request\ of\ Processing\ Rate = \frac{Requests\ from\ x\ number\ of\ devices}{Maximum\ time\ limit} \quad (1)$$

Eq. (2) and Eq. (3) use the two parameters of device connectivity probability and the rate of request arrival to achieve the scalability function.

$$Probability\ Device\ Connectivity = \rho\ devices^{\frac{1}{\tau}} \forall \geq maximum\ connectivity \quad (2)$$

where, $\rho$ = normalization factor $\tau$ = exponent for connectivity.

$$Rate\ of\ arrival = \sum_{i=1}^{number\ of\ devices} rate\ of\ arrival_i \quad (3)$$

Eq. (4), which is based on the above equations, is used to balance the rate at which requests enter and exit the network to reduce delivery delays.

$$balancing\ rate = \begin{cases} Request\ processing\ rate\ X, \max time\ taken\ X\ processing\ tir \\ \frac{(1-\Delta)X\ service\ time}{rate\ of\ arrival\ time}, for\ processed\ requ \end{cases} \quad (4)$$

Recurrent learning is used to manage the discrepancies in the conveyance. By controlling the defects in the hidden layers, the learning process for request processing, and storage optimization are used to obtain the desired outcome, as shown in Fig. 2.

Eq. (5) illustrates how the learning process is used to estimate the prerequisite storage for the request.

$$Required\ Storage = \frac{1}{number\ of\ requests}\log\left(\frac{\frac{1}{l+1}\ request*rate\ of\ arrival}{1-\frac{changes\ on\ request\ rate}{l-1}}\right) \quad (5)$$
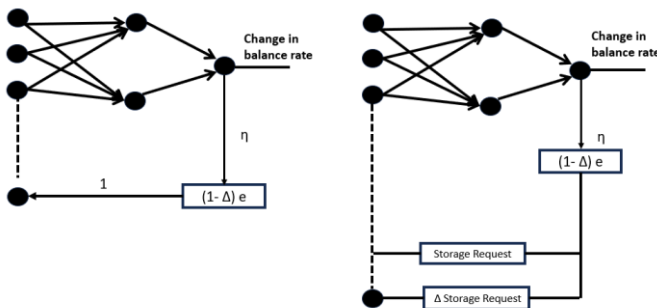


Fig. 2. Recurrent Learning for request processing (left) and storage (right).

## IV. RESULTS AND DISCUSSION

In a network simulator, we conducted the experiment using 200 IoT devices, and the settings used are listed in the table. The evaluation of the established model consistency utilizes metrics like request failure, response time managed and backlogged requests, bandwidth, and storage. The results are compared to those from other approaches to show how robust the intended DECM model is. The parameters and configurations of the experiments are depicted in the Table I.

TABLE I. PARAMETERS AND CONFIGURATION

| Parameters | Configuration |
|---|---|
| Wearable Healthcare Devices | 200 |
| Flow of request | 50 |
| Pause Time | 5ms |
| Bandwidth | 2MBps |
| Maximum Time | 20s |
| Storage size | 60 requests/second |
| Number of requests | 600 requests/second |

A time-based map of how long it took to produce the response is shown in Fig. 3. The backlog is decreased, and the process is sped up as the request is computed, lowering the amount of time that must elapse between requests and the required average response time.
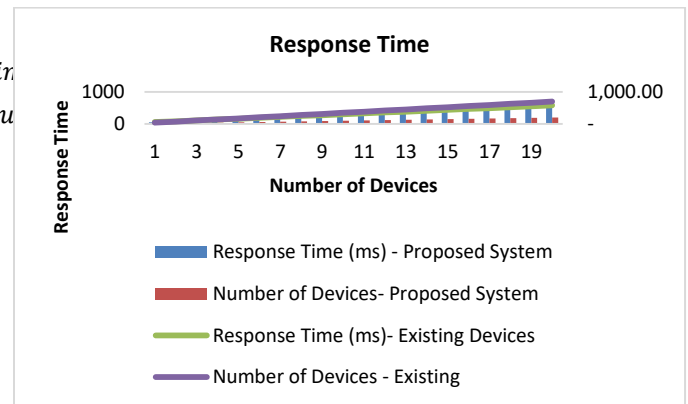


Fig. 3. Response time.

To minimize the time it takes to respond, the balancing rate makes sure that the greatest number of requests may be handled within the allotted service period. The requests are given the appropriate resources with the aid of the storage optimization procedure, which considers the storage units and modifies the succeeding requests.

The resource allocation process is improved, the dormancy in managing the requests is improved, and the count of requests handled and computed by the system is increased, which is used to reduce errors in the requests received and to optimize storage. The table compares the resources handled, the backlogs created, and the failures associated with the current and suggested in Table II.

The resource allocation process is enhanced by the RRL process, which is used to reduce errors in received requests and

to optimize storage. It also improves dormancy in managing requests and increases the count of requests handled and computed by the system's architecture. Table II compares the number of resources handled, the number of backlogs, and the failures suffered in the current and planned designs.

TABLE II. HANDLED REQUESTS, BACKLOGS, AND ERRORS

| Request Handled | Existing | | Proposed | |
|---|---|---|---|---|
| | Failures | Backlogs | Failure | Backlogs |
| 5000 | 0.30 | 400.00 | 0.13 | 166.67 |
| 7000 | 0.34 | 526.32 | 0.15 | 169.49 |
| 9000 | 0.38 | 555.56 | 0.17 | 172.41 |
| 11000 | 0.43 | 588.24 | 0.19 | 175.44 |
| 13000 | 0.49 | 909.09 | 0.21 | 178.57 |
| 15000 | 0.55 | 1,000.00 | 0.24 | 181.82 |
| 17000 | 0.62 | 1,111.11 | 0.27 | 192.31 |
| 19000 | 0.71 | 1,250.00 | 0.31 | 196.08 |
| 21000 | 0.80 | 1,428.57 | 0.35 | 199.20 |
| 23000 | 0.90 | 2,000.00 | 0.39 | 198.81 |

## V. CONCLUSION

The delivery robustness of pervasive computing systems for the Internet of Things wearable devices has been increased because of the DECM introduced in this research in response to earlier work. The approach used computes the requests, optimizes the storage, and helps the flow of requests by removing bottlenecks in their transportation. Additionally, optimized storage distributes the storage for a variety of requests with different densities, preventing bottlenecks in resource allocation. The experiment's findings demonstrate how consistently the suggested architecture works better than the existing one. The future focus of this paper is to create a system with other improvements to help multiple heterogeneous applications run simultaneously.

## ACKNOWLEDGMENT

## REFERENCES

[1] S. Shakya, "Computational Enhancements of Wearable Healthcare Devices on Pervasive Computing System," Journal of Ubiquitous Computing and Communication Technologies (UCCT), vol. 02, no. 02, pp. 98-108, 2020.

[2] A. Dimitria, V. Tsoutsouras, S. Xydis, and D. Soudris, "ECG signal analysis and arrhythmia detection on IoT wearable medical devices," *In 2016 5th International conference on modern circuits and systems technologies (MOCAST)*, pp. 1-4, IEEE, 2016.

[3] H. Mostaga, K. Thurow, and R. Stoll, "Wearable devices in medical internet of things: scientific research and commercially available devices," *Healthcare informatics research*, vol. 23, no. 1, pp. 4-15, 2017.

[4] R. K. Lomotey, J. Pry, and S.Sriramoju, "Wearable IoT data stream traceability in a distributed health information system," *Pervasive and Mobile Computing*, vol. 40, pp. 692-707, 2017.

[5] Z. Al-Makhadmeh, and A. Tolba, "Utilizing IoT wearable medical device for heart disease prediction using higher order Boltzmann model: A classification approach," *Measurement*, 147, pp. 106815, 2019.

[6] M. M. Baig, S. Afifi, H. GholamHosseini, and F. Mirza, "A Systematic Review of Wearable Sensors and IoT-Based Monitoring Applications for Older Adults–a Focus on Ageing Population and Independent Living," *Journal of medical systems*, vol. 43, no. 8, pp. 233, 2019.

[7] Z. Yang, Q. Zhou, L. Lei, W. Xiang, "An IoT-cloud based wearable ECG monitoring system for smart healthcare," *Journal of medical systems*, vol. 40, no. 12, pp. 286, 2016.

[8] De Silva, A. H. T. Eranga, W. H. Peshan Sampath, N. H. Lakshitha Sameera, Y. W. Ranjith Amarasinghe, and A. Mitani, "Development of a wearable tele-monitoring system with IoT for bio-medical applications," *In 2016 IEEE 5th global conference on consumer Electronics*, IEEE, pp. 1-2, 2016.

[9] A. Sabban, "Compact Wearable Meta Materials Antennas for Energy Harvesting Systems, Medical and IOT Systems," *Electronics*, vol. 8, no. 11, pp. 1340, 2019.

[10] N. Dey, A. Ashour, S. J. Fong, and C. Bhatt, "Wearable and Implantable Medical Devices: Applications and Challenges," *Academic Press*, 2019.

[11] S. Balasubramaniam, and R. Kurubarahalli, "IoT-Based Noninvasive Wearable and Remote Intelligent Pervasive Healthcare Monitoring Systems for the Elderly People," *Intelligent Pervasive Computing Systems for Smarter Healthcare*, pp. 141-158, 2019.

[12] J. I. Z. Cheng, L. T. Yeh, "Data Forwarding in Wireless Body Area Networks," *Journal of Electronics and Informatics*, vol. 2, no. 2, 2020.

[13] J. S. Raj, and J. V. Ananthi, "Recurrent Neural Networks and Nonlinear Prediction in Support Vector Machines," *Journal of Soft Computing Paradigm (JSCP)*, vol. 1, no. 01, pp. 33-40, 2019.

# Optimizing Hyperparameters for Improved Melanoma Classification using Metaheuristic Algorithm

Shamsuddeen Adamu[1], Hitham Alhussian[2], Dr. Norshakirah Aziz[3], Dr. Said Jadid Abdulkadir[4], Dr. Ayed Alwadin[5],
Dr. Abdullahi Abubakar Imam[6], Aliyu Garba[7], Yahaya Saidu[8]

Computer Information Science Department, Universiti Teknologi PETRONAS, Seri Iskandar, Malaysia[1, 2, 3, 4, 7]
IAIICT, Ahmadu Bello University, Zaria, Nigeria[1, 7]
Universiti Brunei Darussalam (UBD) Brunei, Darussalam[6]
Computer Science Department Community College, King Saud University, Riyadh, Saudi Arabia[5]

*Abstract*—Melanoma, a prevalent and formidable skin cancer, necessitates early detection for improved survival rates. The rising incidence of melanoma poses significant challenges to healthcare systems worldwide. While deep neural networks offer the potential for precise melanoma classification, the optimization of hyperparameters remains a major obstacle. This paper introduces a groundbreaking approach that harnesses the Manta Rays Foraging Optimizer (MRFO) to empower melanoma classification. MRFO efficiently fine-tunes hyperparameters for a Convolutional Neural Network (CNN) using the ISIC 2019 dataset, which comprises 776 images (438 melanoma, 338 non-melanoma). The proposed cost-effective DenseNet121 model surpasses other optimization methods in various metrics during training, testing, and validation. It achieves an impressive accuracy of 99.26%, an AUC of 99.56%, an F1 score of 0.9091, a precision of 94.06%, and a recall of 87.96%. Comparative analysis with EfficientB1, EfficientB7, EfficientNetV2B0, NesNetLarge, ResNet50, VGG16, and VGG19 models demonstrates its superiority. These findings underscore the potential of the novel MRFO-based approach in achieving superior accuracy for melanoma classification. The proposed method has the potential to be a valuable tool for early detection and improved patient outcomes.*

*Keywords—Deep learning; machine learning; classification; metaheuristic algorithm; CNN*

## I. INTRODUCTION

Skin cancer is characterized by the uncontrolled growth of abnormal cells in the skin's outermost layer (epidermis) due to DNA damage and mutations. Melanoma, a highly aggressive form of skin cancer, is on the rise, posing significant challenges for healthcare systems in terms of early detection and intervention [1]. The precise cause of all melanomas remains unclear, but exposure to ultraviolet (UV) radiation from sunlight or tanning lamps and beds significantly heightens the risk of developing this form of skin cancer [2]. In the United States, the American Cancer Society's estimations predict that approximately 97,610 new cases of melanoma will be diagnosed in the year 2023 [3]. This contrasts with the year 2020, during which a total of 324,635 individuals tested positive for melanoma, with an unfortunate outcome in 57,043 cases, resulting in fatalities [4]. The five-year relative survival rate for melanoma is 93%, with a range of 99% for cases diagnosed at a localized stage (83% of cases) to 27% for cases diagnosed at a faraway stage (4%) [5].

Nevertheless, due to the inherent challenges associated with early detection, both by professionals and patients, there is a pressing need to develop an effective method for the early detection of melanoma and skin cancer. To ensure precise and timely diagnosis, accurate equipment is essential, even in the hands of highly skilled professionals. Dermatologists typically initiate the diagnostic process by employing non-invasive dermoscopy techniques on suspicious areas. However, this conventional method primarily relies on visual examination by the naked eye for preliminary diagnosis. This reliance on visual assessment can introduce challenges, as it can be cumbersome, susceptible to inaccuracies, and dependent on subjective interpretation in a clinical environment [6]. Given these inherent limitations, there is an urgent need to integrate advanced diagnostic tools and technologies to improve the accuracy and efficiency of early melanoma detection.

Deep learning (DL), with its multi-layered artificial neural networks, has ushered in a transformative era in image classification [7]. At the forefront of this revolution are Convolutional Neural Networks (CNNs), renowned for their unparalleled ability to autonomously discern intricate features from raw pixel data [8]. Through iterative training on extensive datasets, DL models refine their parameters to excel in identifying objects and patterns, finding application in diverse domains such as medical imaging [9], autonomous driving [10]. Moreover, in the realm of natural language processing [11]. The exceptional precision and effectiveness of CNNs, particularly in analyzing complex medical images, continue to inspire researchers to leverage them in addressing intricate challenges across various fields.

CNNs have emerged as powerful tools, and researchers often leverage predefined CNN models such as VGG16, VGG19, ResNet, DenseNet, Inception, etc., which come pre-trained on extensive image datasets. These pre-trained models serve as valuable starting points for various image-related tasks, as they have already learned a rich set of features from massive amounts of data. Achieving optimal performance with these models requires careful consideration of hyperparameters, and proper selection of these hyperparameters has a direct impact on the performance of the model [12]. Effective hyperparameter selection stands as a critical endeavor for optimizing a CNN's performance in various applications [13], particularly in the realm of medical imaging, where precise and accurate results are paramount

[14]. Unlocking the full potential of CNNs in this critical domain hinges on the careful process of hyperparameter optimization. To address this challenge, metaheuristic algorithms have emerged as invaluable tools for efficiently searching for optimal hyperparameter values [15]. In contrast to traditional gradient-based optimization methods, such as stochastic gradient descent (SGD), which may struggle with the complex and non-convex landscapes [16] often encountered in medical image analysis, metaheuristics excel. These algorithms, which encompass a range of techniques, including genetic algorithms, particle swarm optimization, simulated annealing, and ant colony optimization, among others, have demonstrated their adaptability and efficiency in exploring and exploiting intricate parameter spaces [17]. In medical imaging, where accuracy and speed are paramount, metaheuristic algorithms offer a promising approach to enhance the capabilities of DL models, ultimately contributing to more accurate disease diagnosis and treatment planning [18].

This study centers on hyperparameter optimization for melanoma classification, employing the DenseNet-121 transfer learning model in tandem with the MRFO metaheuristic algorithm. The principal objective is to elevate melanoma detection accuracy, a pivotal factor in enabling early diagnosis and ultimately improving patient outcomes.

In this study, we make the following significant contributions:

- Novel CNN-Based Framework: A novel CNN framework, developed for reliable classification of Melanoma using the ISIC2019 dataset.

- Transfer Learning Utilization: We utilize ten pre-trained models for transfer learning, benefiting from their knowledge learned on extensive datasets to enhance melanoma classification performance.

- Hyperparameter Optimization: To boost classification performance, we fine-tune hyperparameters for both the CNN model and pre-trained models using the Manta Rays Foraging Optimizer (MRFO) algorithm. This process identifies optimal configurations for each pre-trained model, enhancing melanoma detection performance.

The subsequent sections of this paper are structured as follows:

Section II provides a comprehensive literature review on melanoma classification, offering insights into existing research and methodologies. Section III, a detailed overview of our proposed methodology, outlining the approach to melanoma classification using the CNN framework and the MRFO algorithm. Section IV delves into the experimental results and discussions, shedding light on findings and their implications. Finally, Section V presents conclusions and outlines potential avenues for future research in the field of melanoma classification.

## II. LITERATURE REVIEW

In recent years, there has been a significant surge in the development of algorithms designed for the automated detection of melanoma using dermoscopy images. In the early 2000s, most automated melanoma classification solutions primarily relied on the utilization of manually crafted, low-level features such as shape, color, and texture [19]. However, recent studies, exemplified by [20], have signaled a shift in melanoma identification and recognition methodologies. This transition signifies a departure from the heavy reliance on manual feature engineering, marking a substantial evolution in the field. Presently, there is a noticeable uptick in the adoption of DL approaches for automated skin image analysis [21]. This paradigm shift reflects a move away from manual feature engineering towards methods that harness the capabilities of neural networks to autonomously learn and extract pertinent features from dermoscopy images. This transformation underscores the changing landscape in melanoma classification.

Daghrir et al. [22] introduced an innovative melanoma identification approach by combining three techniques using a majority voting method. Their method incorporates CNN along with two traditional ML approaches, SVM and KNN. These models were trained to recognize specific skin cancer features, including edges, texture, and color characteristics. While this ensemble approach improved overall performance, the combination of results from three different techniques can introduce computational complexity and potentially result in slower processing times. Nevertheless, the results demonstrated that CNN achieved the highest accuracy at 85.5%, followed by SVM with 71.8% accuracy and KNN with 57.3% accuracy.

To address the critical challenge of accurately classifying early Melanoma detection, Golnoori et al. in [23] introduced a novel approach by tackling the persistent complexity of selecting optimal neural network architectures and hyperparameters by employing metaheuristic optimization algorithms to fine-tune both pre-trained and scratch-trained CNN models. These optimized models' deep features were effectively combined and utilized to train a K-nearest neighbors (KNN) classifier. The results of their method demonstrated exceptional performance, achieving an accuracy of 81.6% with an F1-score of 80.9% on the ISIC 2017 dataset and 90.1% accuracy with an 89.8% F1-score on the ISIC 2018 dataset.

Segmentation plays a pivotal role in ML. In their study [24], the authors introduced a technique involving image segmentation. This technique utilizes anisotropic diffusion filtering and a rapid bounding box approach, followed by feature extraction through a hybrid feature extractor (HFE) and a feature extractor based on CNNs. The fusion of these extracted features facilitated the development of a highly accurate classification model capable of distinguishing between melanoma and non-melanoma images. The evaluation, conducted on two datasets, yielded outstanding results, including an accuracy rate of 99.85%, sensitivity of 91.65%, and specificity of 95.70%. These outcomes

underscore the remarkable effectiveness of this approach, surpassing the performance of previous ML algorithms.

To tackle the issue of automated segmentation of melanoma regions, the authors in [25] proposed a DL method based on a deep region-based Convolutional Neural Network (RCNN). This method comprises three main steps: skin refinement, melanoma region localization, and segmentation. The research was evaluated using a dataset consisting of 900 training images and 376 testing images from ISIC 2016 melanoma images. The results highlight the superiority of this approach compared to state-of-the-art techniques, achieving exceptional performance across various evaluation metrics: accuracy (0.94), specificity (0.94), sensitivity (0.97), F1 score (0.96), dice score (0.94), and Jaccard coefficient (0.93).

Ian their study [21], the authors comprehensively analyze the use of pre-trained CNN architectures for melanoma classification. They address a gap in previous research by investigating the specific features extracted by different CNN models. To enhance feature extraction, they introduce boundary localization to preserve critical skin lesion regions. They assess the effectiveness of eight pre-trained CNN models for deep feature extraction from these regions and employ various classifiers for melanoma detection. Across datasets like Ph2, ISIC 2016, ISIC 2017, and HAM10000, their approach achieves high accuracies of 98.33%, 80.47%, 81.16%, and 81%, outperforming state-of-the-art CNN methods.

The authors in [26] introduced a comprehensive three-phase framework for melanoma diagnosis, incorporating data segmentation via an extended Chan-Vese method, data augmentation, and CNN training facilitated by an active learning mini-batch process. To gauge its performance, they conducted an evaluation comparing it with established models such as DenseNet, InceptionV3, MobileNet, NASNet, and Xception. The assessment leveraged Standard Deviation (STD) as a metric to gauge model robustness and stability. The proposed active learning query strategy outperformed baseline methods in both performance and convergence across sixteen image datasets, underscoring the framework's effectiveness in accurate melanoma diagnosis. Nevertheless, the reliance on the active learning mini-batch process may not be universally applicable and may exhibit reduced effectiveness when dealing with imbalanced or noisy datasets.

Adepu et al. [27] present a novel approach for melanoma classification using a lightweight Deep-CNN-based framework. Their methodology incorporates knowledge distillation, Cost-Sensitive Learning with Focal Loss, and in-painting algorithms to enhance classification performance. To improve the model's performance, they introduce new CutOut variations and utilize test time augmentation as regularizers. On the ISIC-2020 dataset, the authors achieve a state-of-the-art result with a sensitivity of 81%, an AUC of 93, and a specificity of 90%. However, as the model processes a larger number of augmented images during each epoch, the use of CutOut may significantly increase the computational cost of training.

The authors in [28] introduce a CAD system utilizing the Online Region-based Active Contour Model (ORACM) to extract the Region of Interest (ROI) from skin lesions. The system demonstrates remarkable performance with an accuracy of 92.24% and perfect specificity and sensitivity (100%). However, it exhibits limitations, such as a heavy reliance on handcrafted features, sensitivity to the initial contour location and manual parameter selection, and the potential for the Non-dominated Sorting Genetic Algorithm (NSGA II) to find local instead of global optimum solutions, resulting in increased computational complexity.

In the realm of lightweight transfer learning models suitable for mobile devices, the study by the authors in [29] introduced the utilization of MobileNetV2 for the classification of melanoma images into benign and malignant categories. Their experiments conducted on multiple melanoma datasets yielded promising results, demonstrating the effectiveness of the proposed method with accuracy rates reaching as high as 85%, outperforming other network architectures. Additionally, the suggested architectural design of the head model, featuring a global average pooling layer followed by two fully-connected layers, not only contributed to high accuracy but also preserved the network's efficiency

The diagnosis of cancer during surgical treatment primarily relies on cancer stage or tumor thickness. In their study[30], the authors introduced two distinct methods aimed at classifying melanoma into two stages: the first stage includes stage 1 and stage 2, while the second encompasses stage 1, stage 2, or stage 3 melanoma. The proposed system employs a CNN, utilizing the Similarity Measure for Text Processing (SMTP) as the loss function. The experimental results include a comparison of various loss functions against the proposed SMTP loss function, demonstrating the superior efficiency of the proposed algorithm when contrasted with several other loss functions tailored for classification tasks.

The authors in [31] introduces a hybrid learning approach for melanoma detection, employing image processing techniques to enhance detection by addressing common issues such as hair, air bubbles, and image noise in dermoscopic images. The study presents an innovative hybrid model, merging DL and machine learning (ML), in its debut for melanoma detection. Performance evaluation on the Hamm 1000 (ISIC 2018) and ISIC 2020 datasets achieves exceptional accuracy scores, reaching 99.44% and 100%, respectively. Notably, the effectiveness of the saturation masking and wavelet transform techniques used may be sensitive to image quality, especially in cases of low resolution, artifacts, or variations in lighting, potentially impacting their noise reduction and lesion prominence enhancement capabilities.

In the study conducted by Nancy [32] presents a two-tier hybrid dual CNN (2-HDCNN) feature fusion approach for malignant melanoma prediction. It first identifies challenging samples, generates a Baseline Segregated Dataset (BSD), and preprocesses it. The second-tier CNN produces bottleneck features, combined with ABCD rule-derived features. These hybrid features are used with various classifiers, resulting in high accuracy (92.15%), precision (96.96%), specificity (96.8%), sensitivity (86.48%), and an AUC of 0.96 for diagnosing malignant melanoma on the ISIC 2018 dataset.

In conclusion, our review of the existing literature in melanoma classification reveals a significant gap in research focused on the optimization of hyperparameters and network structures. While numerous studies have explored ML and DL models for melanoma detection, very few have delved into the critical area of hyperparameter optimization using metaheuristic algorithms. Notably, none of the studies have investigated the potential of the MRFO algorithm in this context. This identified research gap highlights the unexplored potential of MRFO and other metaheuristic algorithms for enhancing the accuracy and efficiency of melanoma classification models.

## III. METHODOLOGY

### A. Introduction

This study introduces a comprehensive framework for melanoma classification Exploiting CNNs alongside transfer learning techniques and MRFO for hyperparameter optimization. The workflow consisting of data acquisition, pre-processing, splitting, classification, and optimization. These phases collectively enable accurate and reliable melanoma classification.

### B. Dataset Description

The ISIC-2019 dataset [33], comprising 25,331 dermoscopy images, is used to evaluate the proposed technique. These images, categorized into eight distinct classes representing different types of skin lesions, exhibit varying dimensions, ranging from 600x450 to 1024x1024 pixels. In our evaluation, a total of 776 images are employed, including 438 melanoma and 338 non-melanoma cases.

### C. DenseNet-121 Architecture

DenseNet121, a CNN architecture renowned for its effectiveness in visual object recognition, achieves state-of-the-art results with reduced parameters by intricately connecting each layer to both preceding and subsequent layers [34].
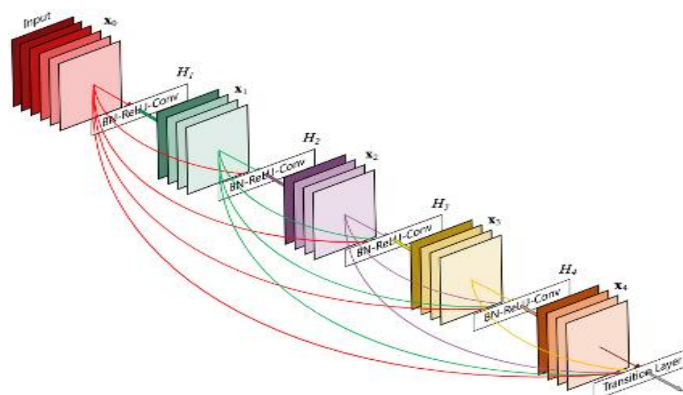


Fig. 1. DenseNet121 architecture.

DenseNet-121, one of several variants within the DenseNet family, is characterized by five convolution and pooling layers, three transition layers (at depths 6, 12, and 24), one classification layer (at depth 16), and two dense blocks employing 1x1 and 3x3 convolutions. Fig. 1 shows DenseNet121 architecture.

$$\text{Total Layers} = 5 + (6 + 12 + 24 + 16) \times 2 = 121$$

In total, DenseNet-121 comprises 121 layers, making it a versatile choice for various computer vision tasks. This study specifically employs DenseNet-121 due to its compelling advantages, such as mitigating the vanishing-gradient problem, enhancing feature propagation, promoting feature reuse, and notably reducing the overall model parameter count [35]

### D. Hyperparameter Selection

The study focuses on optimizing several critical hyperparameters to enhance model performance:

- Loss Function: Defines the loss metric used for model optimization.

- Training Batch Size: Determines the number of samples used in each training iteration.

- Model Dropout Ratio: Regulates the extent of regularization during training.

- Transfer Learning Ratio: Controls the extent of pre-trained weight utilization.

- Optimizer: Selects the optimization algorithm.

- Rotation Angle: Diversifies training data by simulating different lesion orientations.

- Shifts (Width and Height): Handles variations in lesion position and image composition.

- Zoom Level: Allows the model to learn features at various scales within images.

- Shear Transformation: Introduces controlled deformations to enhance the model's adaptability.

- Flipping: Simulates mirrored images (Horizontal and Vertical).

These hyperparameters collectively contribute to the adaptability, generalization, and optimization of the model for melanoma classification. Next steps involve leveraging the MRFO [36]. Metaheuristic Algorithm to fine-tune these hyperparameters systematically, ensuring that the model achieves the best possible results in the challenging task of classifying melanoma.

### E. Manta Ray Foraging Metaheuristic Algorithm

The MRFO [36] algorithm incorporates three foraging behaviors: chain foraging, cyclone foraging, and somersault foraging. These behaviors are mathematically modeled as follows:

- Chain foraging: - In the MRFO [36] Chain foraging: Manta rays use their ability to detect plankton concentration to navigate towards better positions. The algorithm assumes the highest plankton concentration represents the best solution found so far. Manta rays form a foraging chain, moving towards both the food and the individual in front of them.

$$x_i^d(t+1) = \begin{cases} x_i^d(t) + r * (x_{i-1}^d(t) - x_i^d(t)) + \\ \quad \alpha * \left(x_{best}^d(t) - x_i^d(t)\right) i = 1 \\ \\ x_i^d(t) + r * (x_{i-1}^d(t) - x_i^d(t)) + \\ \quad \alpha * \left(x_{best}^d(t) - x_i^d(t)\right) i = 2, \dots N \end{cases} \quad (1)$$

$$\alpha = 2 * r * \sqrt{|\log(r)|} \quad (2)$$

In dimension $d^{th}$, $x_i^d(t)$ represents the $i^{th}$ individual's position at time (t) with r as a random vector between 0 and 1, α as a weighting coefficient, and $x_{best}^d(t)$ denoting a high-plankton concentration area. Fig. 2 illustrates the two-dimensional foraging behavior of individuals. An individual's position update depends on the previous $(i-1)^{th}$ individual's current position, $x_{i-1}^d(t)$, and the food source position, $x_{best}^d(t)$.

- Cyclone foraging: - Manta rays display a distinctive foraging behavior in which they form a long chain and spiral toward plankton patches in deep waters. This spiral foraging strategy resembles that seen in WOA [37]. In the case of cyclone foraging, manta ray swarms spiral towards food while also moving toward the ray in front, forming a line that takes on a spiral shape. Fig. 3 illustrates this cyclone foraging behavior in a 2-dimensional context. Swarm members follow the leader, traversing a spiral path toward food. The mathematical equation for modeling this two-dimensional spiral movement of manta rays is as follows:

$$\begin{cases} X_i(t+1) = X_{best} + r * \left(X_{i-1}(t) - X_i(t)\right) + \\ \quad e^{bw} * \cos(2\pi\omega) * \left(X_{best} - X_i(t)\right) \\ \\ X_i(t+1) = X_{best} + r * \left(X_{i-1}(t) - X_i(t)\right) + \\ \quad e^{bw} * \cos(2\pi\omega) * \left(X_{best} - X_i(t)\right) \end{cases} \quad (3)$$

Where, w is a random number between 0 and 1.

This behavior can extend to n-dimensional space. The mathematical model for cyclone foraging is defined as follows:

$$x_i^d(t+1) = \begin{cases} x_{best}^d + r * \left(x_{best}^d(t) - x_i^d(t)\right) + \\ \quad \beta * \left(x_{best}^d(t) - x_i^d(t)\right) i = 1 \\ \\ x_{best}^d + r * \left(x_{i-1}^d(t) - x_i^d(t)\right) + \\ \quad \beta * \left(x_{best}^d(t) - x_i^d(t)\right) i = 2, \dots n \end{cases} \quad (4)$$

$$\beta = 2e^{r1\frac{T-t+1}{T}} * \sin(2\pi r_1) \quad (5)$$

In the cyclone foraging strategy, individuals perform random searches relative to the food source as their reference point, promoting both exploitation and exploration. To encourage exploration, each individual is directed to seek a new position in the search space, away from the current best position, using a new random reference point. This approach

enhances exploration, enabling the MRFO [36] algorithm to perform a broad global search. The mathematical equation is as follows:

β is the weight coefficient, T is the maximum number of iterations, and $r_1$ is a random number in [0, 1].

$$x_{rand}^d = Lb^d + r (Ub^d - Lb^d) \quad (6)$$

$$(t+1) = \begin{cases} x_{rand}^d + r * \left(x_{rand}^d(t) - x_i^d(t)\right) \\ \quad + \beta * \left(x_{rand}^d(t) - x_i^d(t)\right) i = 1 \\ \\ x_{rand}^d + r * \left(x_{i-1}^d(t) - x_i^d(t)\right) + \beta \\ \quad * \left(x_{rand}^d(t) - x_i^d(t)\right) i = 2, \dots n \end{cases} \quad (7)$$

where, $x_{rand}^d$ is a random position randomly produced in the search space, $Ub^d$, $Lb^d$ are the upper and lower limits of the $d^{th}$ dimension respectively.
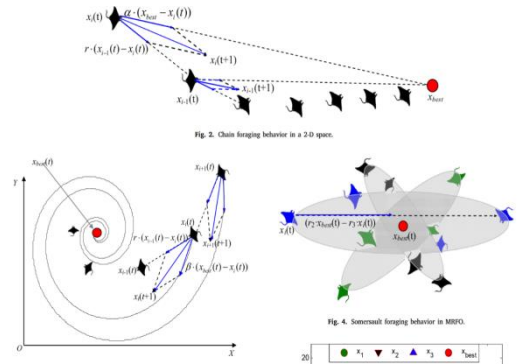


Fig. 2. MRFO (1) Chain (2) Cyclone (3) Somersault behavior in a 3-D space.

- Cyclone foraging: - This behavior treats the food source position as a pivot, causing individuals to swim in a back-and-forth manner while somersaulting to new positions. This results in continuous position updates around the current best solution. The mathematical equation below models this behavior.

$$x_i^d(t+1) = x_i^d(t) + S * \left(r_2 * x_{best}^d - r_3 * x_i^d(t)\right) i = 1, 2, \dots n \quad (8)$$

The somersault factor (S = 2) determines the range of somersaulting for manta rays using random numbers (r1 and r2) in [0, 1]. Eq. (8) allows each individual to move within a new search domain, symmetrically positioned around the best solution found so far. As an individual approaches the optimal solution, the somersault range decreases, guiding all individuals toward convergence. This adaptive reduction occurs as iterations increase. Fig. 4 visually illustrates somersault foraging behavior in MRFO [36].

Like other metaheuristic optimizers, MRFO [36] begins with a random population. In each iteration, individuals update positions relative to neighbors and a reference point. The exploration-exploitation balance is controlled by t/T, decreasing from 1 to t/T. When t/T < rand, the best solution is used for exploitation; otherwise, a random position aids

exploration. Chain and cyclone foraging alternate randomly, while somersault foraging adapts positions to the best solution. This iterative process continues until the stopping criterion is met, yielding the best individual's position and fitness value.

Three individuals undergo 100 iterations in the search space using Eq. (8). Randomly sampled points distribute between current positions and their symmetrical positions around xbest. As distance to xbest decreases, the number of sampled points reduces. Dense points around xbest aid exploitation, while sparse ones promote exploration.

### F. Hyperparameter Optimization Process

*1) Data preprocessing*: After acquiring the dataset, it underwent a series of preprocessing steps involving four key techniques: image resizing, dimensional scaling, data balancing, and data augmentation. In the image processing phase, a two-step approach was utilized to standardize the various image dimensions. Initially, the color space conversion from BGR to RGB was executed to ensure consistent color representation. Subsequently, bicubic interpolation [38] resizing was applied to all images, harmonizing them to a uniform size of (32x32x3) pixels. This process established consistency, laying a solid foundation for subsequent analysis. Addressing the issue of data imbalance [39], the study employed data augmentation techniques encompassing width and height shifting, shearing, rotation, horizontal and vertical flipping, and zooming. These techniques help diversify the dataset and mitigate potential misclassification or overfitting during training and optimization phases [40]. Additionally, the dataset was partitioned into an 80% training subset and a 20% validation subset to facilitate model training and evaluation. This division ensures a robust assessment of model performance and generalizability.

*2) Classification and optimization*: The optimization process commences with the creation of an initial solution population represented as vectors. Each vector element corresponds to a specific hyperparameter, such as dropout ratio, optimizers, batch size, etc. In this study, 12 well-defined hyperparameters are targeted for optimization, as outlined in Table I. The dimensionality of solution vectors depends on the application of data augmentation.

*a) Fitness Function and Hyperparameter Mapping*: At the core of the optimization process, the fitness function is utilized to assess the quality of each population solution. This function encompasses three crucial steps:

- Hyperparameter Mapping: To effectively configure the pre-trained transfer learning model, solution elements are mapped to their corresponding actual hyperparameters.

- Top of Form

- Model Creation and Preparation: With mapped hyperparameters, the pre-trained transfer learning CNN model is created and compiled. A diverse set of pre-

trained models, including DenseNet121, EfficientB1, EfficientB7, EfficientV2B0, MobileNet, NesNetLarge, ResNet50, VGG16, and VGG19, are harnessed in this study.

- Model Training and Evaluation: Following model creation, the training phase commences, allowing the model to learn from the data. Training progresses for a predetermined number of epochs typically set to 1000 in this study.

*b) Balancing Exploration and Exploitation*: This approach dynamically traverses the hyperparameter space, striving for a harmonious balance between exploration and exploitation. This equilibrium proves pivotal in uncovering globally optimal solutions. The process iteratively refines the population, gradually converging towards configurations that yield superior model performance.

Fig. 3 depicts the model architecture employed in our optimization process, offering a visual representation of the complex interplay between hyperparameters, fitness evaluation, and model creation.

TABLE I. HYPERPARAMETER SETTINGS

| Hyperparameters Settings | | |
|---|---|---|
| S/noo | Hyperparameter | Values |
| 1 | Loss Function | Binary Crossentropy |
| 2 | Training batch size | [8, 16,32,64] |
| 3 | Model dropout ratio | [0- 0.5] |
| 4 | Transfer learning ratio | 0-26 (step = 1) |
| 5 | optimizer | [Adam(), Nadam(), RMSprop(), Adadelta(), Adagrad(), SGD()] |
| 6 | Rotation Range | 0 - 40 (step = 1) |
| 7 | width shift value. | [0 - 0.2] |
| 8 | Hight shift value. | [0 - 0.2] |
| 9 | Shear | [0 - 0.2] |
| 10 | Zoom | [0 - 0.2] |
| 11 | Horizontal Flipping | [Yes, No] |
| 12 | Vertical flipping | [Yes, No] |
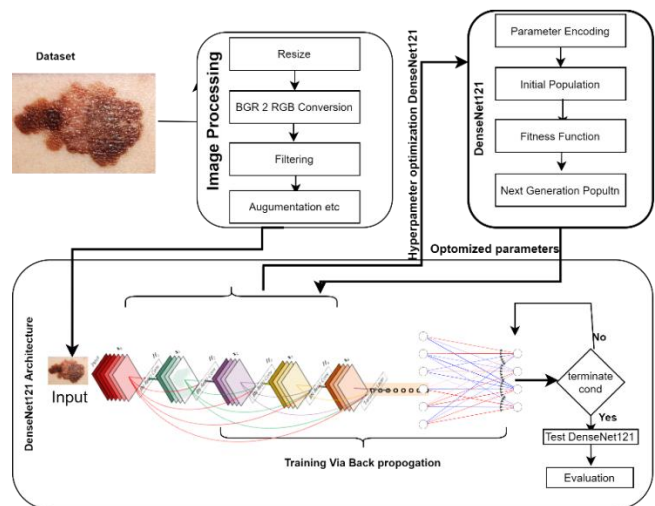


Fig. 3.   Proposed model architecture.

## G. Evaluation Metrics

The proposed model will undergo evaluation using standard assessment metrics, including Accuracy, Precision, Recall, and F-Score, as mentioned in [38]–[41].

## H. Software and Tools

The experiments were conducted in Python, utilizing popular libraries including Keras, Scikit-learn, and OpenCV. The computational environment employed a Dell system equipped with an Intel Xeon CPU, boasting up to 128GB of memory, and a spacious 1TB SSD.

## IV. RESULT AND DISCUSSION

In this section, the proposed model was assessed through a comparison with four nature-inspired techniques (GA, WOA, GWO, WHO) and benchmarked against eight state-of-the-art deep learning architectures (EfficientB1, EfficientB7, EfficientV2B0, MobileNet, NesNetLarge, ResNet50, VGG16, and VGG19) on the ISIC 2019 dataset. This dataset comprises 776 skin lesion images encompassing melanoma and non-melanoma classes.

Data preprocessing was undertaken, including augmentation to expand the dataset to 8000 images, and an 80%-20% random split was applied for training and validation purposes. For image resizing, bilinear interpolation was utilized. The experiments were conducted using the Keras library with the hyperparameters detailed in Table I.

The model is comprised of 7.2 million parameters, which includes 121 convolutional layers and three fully connected layers. Training was executed over 1000 epochs, involving 12 distinct hyperparameter configurations and the incorporation of early stopping with a patience of 15.

Proposed model performance across top 10 epochs

Top of Form

In Table II, we observed that the model's performance across the top 10 epochs consistently exhibited high accuracy, ranging from 0.9908 to 0.9926, and AUC, ranging from 0.9898 to 0.9974. Additionally, precision, recall, and the F1-Score consistently demonstrated strong values, indicating proficient classification capabilities with minimal discrepancies. These results underscore the model's robust and stable performance, making it well-suited for accurate for melanoma classification.

TABLE II. PERFORMANCE OF PROPOSED MODEL ACROSS TOP 10 EPOCHS

| Epoch | Accuracy | AUC | Precision | Recall | F1-Score | Loss |
|---|---|---|---|---|---|---|
| 38 | 0.9926 | 0.9956 | 0.9406 | 0.8796 | 0.9091 | 0.0217 |
| 37 | 0.9924 | 0.9974 | 0.9447 | 0.8704 | 0.906 | 0.0216 |
| 34 | 0.9916 | 0.9952 | 0.9529 | 0.8426 | 0.8943 | 0.0241 |
| 35 | 0.9916 | 0.9951 | 0.9261 | 0.8704 | 0.8974 | 0.0244 |
| 40 | 0.9914 | 0.9937 | 0.9343 | 0.8565 | 0.8937 | 0.0224 |
| 33 | 0.9912 | 0.9974 | 0.9430 | 0.8426 | 0.89 | 0.0237 |
| 25 | 0.9910 | 0.9900 | 0.9381 | 0.8426 | 0.8878 | 0.0331 |
| 32 | 0.9908 | 0.9942 | 0.9378 | 0.8380 | 0.8851 | 0.0259 |
| 36 | 0.9908 | 0.9898 | 0.9163 | 0.8611 | 0.8878 | 0.0283 |

Model Validation Performance Across Top 10 Epochs

In correspondence to Table III, the model consistently demonstrates strong validation performance, with accuracy ranging from 0.9586 to 0.9734 and AUC values between 0.8164 and 0.8588. Validation loss falls in the range of 0.1458 to 0.2014, indicating close alignment with the ground truth. Precision values consistently exceed 0.5, indicating minimal false positives, while recall values vary, indicating the model's ability to correctly identify positive samples. These findings highlight the model's robust and consistent validation performance, ideal for tasks demanding accurate classification.

TABLE III. VALIDATION PERFORMANCE ACROSS TOP 10 EPOCHS

| Epoch | Val. Acc | Val AUC | Val Prec. | Val recall | F1-Score | Val Loss |
|---|---|---|---|---|---|---|
| **38** | **0.9680** | **0.8179** | **0.6857** | **0.4444** | **0.5393** | **0.1980** |
| 37 | 0.9688 | 0.8519 | 0.7059 | 0.4444 | 0.5455 | 0.1521 |
| 34 | 0.9711 | 0.8164 | 0.8148 | 0.4074 | 0.5432 | 0.1652 |
| 35 | 0.9586 | 0.8588 | 0.5085 | 0.5556 | 0.531 | 0.1660 |
| 40 | 0.9688 | 0.8258 | 0.7333 | 0.4074 | 0.5238 | 0.2014 |
| 33 | 0.9695 | 0.8353 | 0.7419 | 0.4259 | 0.5412 | 0.1774 |
| 25 | 0.9734 | 0.8502 | 0.8333 | 0.4630 | 0.5952 | 0.1458 |
| 32 | 0.9719 | 0.8396 | 0.8462 | 0.4074 | 0.55 | 0.1692 |
| 36 | 0.9664 | 0.8288 | 0.6774 | 0.3889 | 0.4941 | 0.1653 |

From Fig. 4, the performance of DenseNet121 model was evaluated under three different scenarios: 100 epochs with a 5000-sample dataset, 500 epochs with an 8000-sample dataset, and 1000 epochs with an 8000-sample dataset. The model with 1000 epochs on the larger dataset demonstrated the highest accuracy (99.26%), AUC (99.56%), and F1-Score (0.9091), indicating its superior ability to classify positive and negative instances. It also achieved the lowest loss (0.0217) and high precision (94.06%) and recall (87.96%) values. It is observed that increasing the number of training epochs and dataset size consistently leads to better model performance across various metrics.
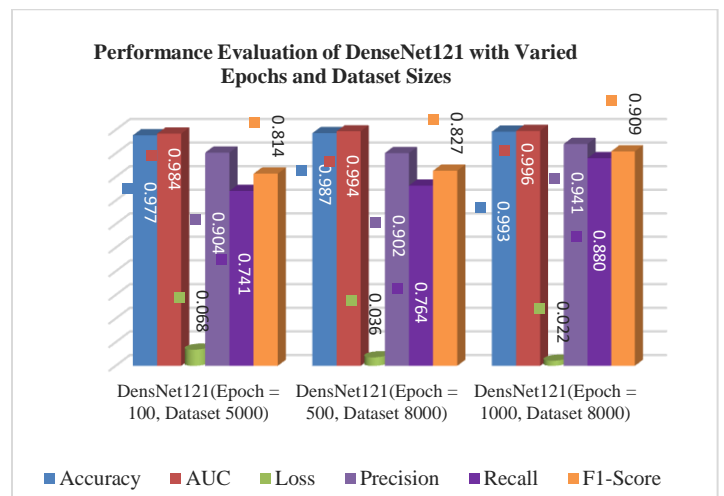


Fig. 4. Comparison with different configuration.

Comparative Analysis of the Proposed Model and Other Architectures

TABLE IV.    COMPARATIVE ANALYSIS OF MODEL PERFORMANCE

| Model | Accuracy | AUC | F1-Score | Precision | Recall | Loss |
|---|---|---|---|---|---|---|
| **Proposed Model** | 0.9926 | 0.9956 | 0.9091 | 0.9406 | 0.8796 | 0.0217 |
| **EfficientB1** | 0.9580 | 0.4972 | 0.0092 | 1.0000 | 0.0046 | 0.1815 |
| **EfficientB7** | 0.9232 | 0.4824 | 0.1495 | 0.5000 | 0.0879 | 0.6742 |
| **EfficientNetV2B0** | 0.9304 | 0.5135 | 0.1946 | 0.6098 | 0.1157 | 0.6694 |
| **MobileNet** | 0.9910 | 0.9980 | 0.9012 | 0.9397 | 0.8657 | 0.0221 |
| **NesNetLarge** | 0.6911 | 0.7096 | 0.5127 | 0.6547 | 0.4213 | 0.6968 |
| **ResNet50** | 0.9656 | 0.9134 | 0.4013 | 0.7564 | 0.2731 | 0.1076 |
| **VGG16** | 0.9865 | 0.9937 | 0.8244 | 0.9152 | 0.7500 | 0.0369 |
| **VGG19** | 0.9797 | 0.9675 | 0.7263 | 0.8415 | 0.6389 | 0.0628 |

The presented data showcases the performance evaluation of the proposed model (see Table IV) in comparison to several established DL architectures across various metrics. The proposed model outperforms all other models with an impressive accuracy of 99.26%, an AUC of 99.56%, and a commendable F1-Score of 0.9091. Furthermore, it exhibits a high precision of 94.06% and recall of 87.96%, indicating its robustness in correctly classifying positive instances while minimizing false positives. In contrast, models like EfficientB1, EfficientB7, EfficientNetV2B0, NesNetLarge, ResNet50, VGG16, and VGG19 show lower accuracy and F1-Scores, reflecting their limitations in effectively handling the given task. MobileNet, while achieving a high accuracy and AUC, falls slightly behind the proposed model in F1-Score, precision, and recall. These results underscore the superior performance of the proposed model in comparison to established architectures, demonstrating its potential for melanoma classification. Additionally, the low loss value of 0.0217 for the proposed model further confirms its proficiency in minimizing prediction errors during training.
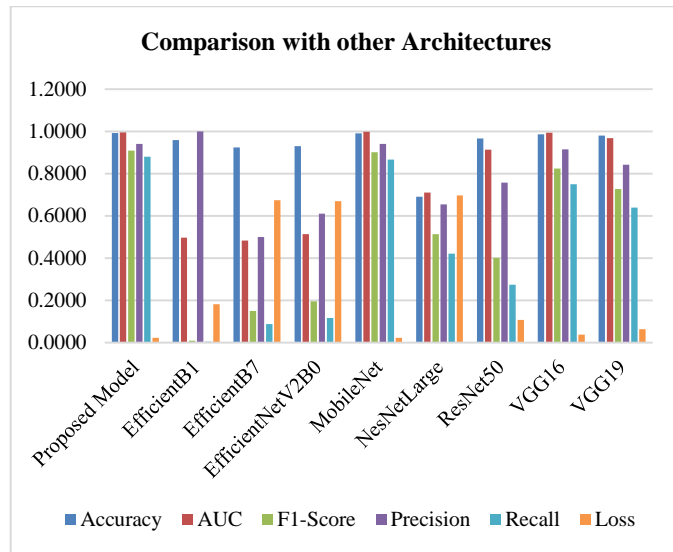


Fig. 5.    Comparison with other architectures.

Table V shows the In-Depth Analysis of Proposed DensNet121 Model in Comparison with Prior Literature.

TABLE V.    ANALYSIS OF PROPOSED MODEL IN COMPARISON WITH PRIOR LITERATURE

| Reference | Model | Metaheuristics | Accuracy | Precision | Recall | F1_Score |
|---|---|---|---|---|---|---|
| [42] | CNN | GWO | 98.3 | | | |
| [43] | CNN | WHO | 96.0 | | | |
| [23] | ALexNet | GA | 0.8166 | 0.8118 | 0.8167 | 0.8092 |
| [23] | CNN | PSO | 90.01 | 0.0.898 | 0.90 | 0.897 |
| Proposed Model | DensNet121 | MRFO | 0.9926 | 0.9406 | 0.8796 | 0.9091 |

In comparison with other literature, the proposed DensNet121-based model optimized with MRFO exhibits superior performance. Fig. 5 shows the comparison with other architectures. It achieves an accuracy of 99.26%, surpassing previous models utilizing different metaheuristics such as GWO (98.3%) and WHO (96%). Moreover, the proposed model's precision (0.9406) and recall (0.8796) outperform an AlexNet model optimized with GA (accuracy: 81.66%, precision: 81.18%, recall: 81.67%). Additionally, the F1-Score of the proposed model (0.9091) exceeds that of a CNN optimized with PSO (accuracy: 90.01%, F1-Score: 0.897). These findings highlight the effectiveness of the proposed model in achieving superior accuracy and a balanced precision-recall trade-off when compared to existing literature.

## V.    CONCLUSION

In conclusion, the manual classification of melanoma from dermoscopic images presents significant challenges, even for experts, highlighting the pressing need for efficient automation solutions. This paper introduces an automated and cost-effective model built upon the DenseNet121 architecture, harnessed by the MRFO metaheuristic algorithm for melanoma classification. Through careful optimization of critical CNN hyperparameters, this model significantly enhances the architecture's ability to tackle melanoma classification effectively.

The study employs data preprocessing techniques, including bilinear interpolation-based image resizing, and adeptly encodes CNN hyperparameters to facilitate optimization. To validate the model's efficacy, a comprehensive evaluation was conducted, comparing it with hyperparameter optimization techniques GA, PSO, GWO and WHO on the ISIC skin cancer dataset. Additionally, the model was benchmarked against eight state-of-the-art deep learning

architectures (EfficientB1, EfficientB7, EfficientV2B0, MobileNet, NesNetLarge, ResNet50, VGG16, and VGG19).

The final results demonstrated the superiority of our proposed model in terms of accuracy, AUC, precision, F1 Score and loss rates during training, testing, and validation phases, surpassing the performance of other optimization methods explored in this experiment.

As a direction for future research, further refinement and exploration of this model can lead to even more robust and accurate melanoma classification systems, potentially contributing to early diagnosis and improved patient outcomes in the field of dermatology.

## REFERENCES

[1] N. L. Bolick and A. C. Geller, "Epidemiology of Melanoma," Hematol. Oncol. Clin. North Am., vol. 35, no. 1, pp. 57–72, 2021, doi: 10.1016/j.hoc.2020.08.011.

[2] "Melanoma," 2023. https://www.mayoclinic.org/diseases-conditions/melanoma/symptoms-causes/syc-20374884 (accessed Sep. 09, 2023).

[3] B. N. E. Cancer, "Melanoma: Statistics," 2023. https://www.cancer.net/cancer-types/melanoma/statistics (accessed Sep. 09, 2023).

[4] C. N. E. Board, "Cancer Net," 2023. https://www.cancer.net/cancer-types/skin-cancer-non-melanoma/statistics (accessed May 17, 2023).

[5] World Cancer Research Fund, "Cancer Facts and Figures 2021," World Cancer Research Fund International. pp. 1–4, 2021. [Online]. Available: http://www.wcrf.org/int/cancer-facts-figures/worldwide-data

[6] J. A. Fee, F. P. McGrady, and N. D. Hart, "Dermoscopy use in primary care: a qualitative study with general practitioners," BMC Prim. Care, vol. 23, no. 1, pp. 1–10, 2022, doi: 10.1186/s12875-022-01653-7.

[7] J. Chai, H. Zeng, A. Li, and E. W. T. Ngai, "Deep learning in computer vision: A critical review of emerging techniques and application scenarios," Mach. Learn. with Appl., vol. 6, p. 100134, 2021, doi: https://doi.org/10.1016/j.mlwa.2021.100134.

[8] R. Yamashita, M. Nishio, R. K. G. Do, and K. Togashi, "Convolutional neural networks: an overview and application in radiology," Insights Imaging, vol. 9, no. 4, pp. 611–629, 2018, doi: 10.1007/s13244-018-0639-9.

[9] L. Cai, J. Gao, and D. Zhao, "A review of the application of deep learning in medical image classification and segmentation," Ann. Transl. Med. Vol 8, No 11 (June 15, 2020) Ann. Transl. Med., 2020, [Online]. Available: https://atm.amegroups.org/article/view/36944

[10] I. Sonata, Y. Heryadi, L. Lukas, and A. Wibowo, "Autonomous car using CNN deep learning algorithm," J. Phys. Conf. Ser., vol. 1869, no. 1, 2021, doi: 10.1088/1742-6596/1869/1/012071.

[11] W. Wang and J. Gang, "Application of Convolutional Neural Network in Natural Language Processing," in 2018 International Conference on Information Systems and Computer Aided Education (ICISCAE), 2018, pp. 64–70. doi: 10.1109/ICISCAE.2018.8666928.

[12] L. Yang and A. Shami, "On hyperparameter optimization of machine learning algorithms: Theory and practice," Neurocomputing, vol. 415, pp. 295–316, 2020, doi: https://doi.org/10.1016/j.neucom.2020.07.061.

[13] M. Wojciuk, Z. Swiderska-Chadaj, K. Siwek, and A. Gertych, "The Role of Hyperparameter Optimization in Fine-Tuning Of Cnn Models," SSRN Electron. J., 2022, doi: 10.2139/ssrn.4087642.

[14] A. W. Salehi et al., "A Study of CNN and Transfer Learning in Medical Imaging: Advantages, Challenges, Future Scope," Sustainability, vol. 15, no. 7. 2023. doi: 10.3390/su15075930.

[15] A. Gogna and A. Tayal, "Metaheuristics: review and application," J. Exp. \& Theor. Artif. Intell., vol. 25, no. 4, pp. 503–526, 2013, doi: 10.1080/0952813X.2013.782347.

[16] R. Chen, X. Tang, and X. Li, "Adaptive Stochastic Gradient Descent Method for Convex and Non-Convex Optimization," Fractal and Fractional, vol. 6, no. 12. 2022. doi: 10.3390/fractalfract6120709.

[17] M. Abdel-Basset, L. Abdel-Fatah, and A. K. Sangaiah, Metaheuristic algorithms: A comprehensive review. Elsevier Inc., 2018. doi: 10.1016/B978-0-12-813314-9.00010-4.

[18] Y. Kumar, A. Koul, R. Singla, and M. F. Ijaz, "Artificial intelligence in disease diagnosis: a systematic literature review, synthesizing framework and future research agenda.," J. Ambient Intell. Humaniz. Comput., vol. 14, no. 7, pp. 8459–8486, 2023, doi: 10.1007/s12652-021-03612-z.

[19] A. K. Adepu, S. Sahayam, U. Jayaraman, and R. Arramraju, "Melanoma classification from dermatoscopy images using knowledge distillation for highly imbalanced data," Comput. Biol. Med., vol. 154, no. July 2022, p. 106571, 2023, doi: 10.1016/j.compbiomed.2023.106571.

[20] E. Yang et al., "Machine learning modeling and prognostic value analysis of invasion-related genes in cutaneous melanoma," Comput. Biol. Med., vol. 162, no. March, p. 107089, 2023, doi: 10.1016/j.compbiomed.2023.107089.

[21] H. K. Gajera, D. R. Nayak, and M. A. Zaveri, "A comprehensive analysis of dermoscopy images for melanoma detection via deep CNN features," Biomed. Signal Process. Control, vol. 79, no. P2, p. 104186, 2023, doi: 10.1016/j.bspc.2022.104186.

[22] J. Daghrir, L. Tlig, M. Bouchouicha, and M. Sayadi, "Melanoma skin cancer detection using deep learning and classical machine learning techniques: A hybrid approach," 2020 Int. Conf. Adv. Technol. Signal Image Process. ATSIP 2020, no. C, pp. 3–7, 2020, doi: 10.1109/ATSIP49331.2020.9231544.

[23] F. Golnoori, F. Z. Boroujeni, and A. Monadjemi, "Metaheuristic algorithm based hyper-parameters optimization for skin lesion classification," Multimed. Tools Appl., vol. 82, no. 17, pp. 25677–25709, 2023, doi: 10.1007/s11042-023-14429-7.

[24] M. Rahman, M. K. Nasir, and S. I. Khan, "Hybrid Feature Fusion and Machine Learning Approaches for Melanoma Skin Cancer Detection," no. January, 2022, doi: 10.20944/preprints2.

[25] N. Nida, A. Irtaza, A. Javed, M. H. Yousaf, and M. T. Mahmood, "Melanoma lesion detection and segmentation using deep region based convolutional neural network and fuzzy C-means clustering," Int. J. Med. Inform., vol. 124, no. January, pp. 37–48, 2019, doi: 10.1016/j.ijmedinf.2019.01.005.

[26] E. Pérez and S. Ventura, "A framework to build accurate Convolutional Neural Network models for melanoma diagnosis," Knowledge-Based Syst., vol. 260, p. 110157, 2023, doi: 10.1016/j.knosys.2022.110157.

[27] A. K. Adepu, S. Sahayam, U. Jayaraman, and R. Arramraju, "Melanoma classification from dermatoscopy images using knowledge distillation for highly imbalanced data," Comput. Biol. Med., vol. 154, no. July 2022, p. 106571, 2023, doi: 10.1016/j.compbiomed.2023.106571.

[28] S. Salem Ghahfarrokhi, H. Khodadadi, H. Ghadiri, and F. Fattahi, "Malignant melanoma diagnosis applying a machine learning method based on the combination of nonlinear and texture features," Biomed. Signal Process. Control, vol. 80, no. P1, p. 104300, 2023, doi: 10.1016/j.bspc.2022.104300.

[29] R. Indraswari, R. Rokhana, and W. Herulambang, "Melanoma image classification based on MobileNetV2 network," Procedia Comput. Sci., vol. 197, pp. 198–207, 2021, doi: 10.1016/j.procs.2021.12.132.

[30] R. Patil and S. Bellary, "Machine learning approach in melanoma cancer stage detection," J. King Saud Univ. - Comput. Inf. Sci., vol. 34, no. 6, pp. 3285–3293, 2022, doi: 10.1016/j.jksuci.2020.09.002.

[31] Ç. Suiçmez, H. Tolga Kahraman, A. Suiçmez, C. Yılmaz, and F. Balcı, "Detection of melanoma with hybrid learning method by removing hair from dermoscopic images using image processing techniques and wavelet transform," Biomed. Signal Process. Control, vol. 84, no. July 2022, 2023, doi: 10.1016/j.bspc.2023.104729.

[32] Y. Nancy Jane, S. K. Charanya, M. Amsaprabhaa, P. Jayashanker, and K. Nehemiah H., "2-HDCNN: A two-tier hybrid dual convolution neural network feature fusion approach for diagnosing malignant melanoma," Comput. Biol. Med., vol. 152, no. November 2022, p. 106333, 2023, doi: 10.1016/j.compbiomed.2022.106333.

[33] "ISIC2019." https://challenge.isic-archive.com/data/#2019 (accessed Feb. 04, 2023).

[34] N. Hasan, Y. Bao, A. Shawon, and Y. Huang, "DenseNet Convolutional Neural Networks Application for Predicting COVID-19 Using CT

Image," SN Comput. Sci., vol. 2, no. 5, p. 389, 2021, doi: 10.1007/s42979-021-00782-7.

[35] G. Huang, Z. Liu, L. Van Der Maaten, and K. Q. Weinberger, "Densely connected convolutional networks," Proc. - 30th IEEE Conf. Comput. Vis. Pattern Recognition, CVPR 2017, vol. 2017-Janua, pp. 2261–2269, 2017, doi: 10.1109/CVPR.2017.243.

[36] W. Zhao, Z. Zhang, and L. Wang, "Manta ray foraging optimization: An effective bio-inspired optimizer for engineering applications," Eng. Appl. Artif. Intell., vol. 87, no. September 2019, p. 103300, 2020, doi: 10.1016/j.engappai.2019.103300.

[37] S. Mirjalili and A. Lewis, "The Whale Optimization Algorithm," Adv. Eng. Softw., vol. 95, pp. 51–67, 2016, doi: 10.1016/j.advengsoft.2016.01.008.

[38] R. L. Siegel, K. D. Miller, H. E. Fuchs, and A. Jemal, "Cancer Statistics, 2021," CA. Cancer J. Clin., vol. 71, no. 1, pp. 7–33, 2021, doi: 10.3322/caac.21654.

[39] C. Szegedy et al., "Going Deeper with Convolutions," pp. 1–9, 2015.

[40] V. Badrinarayanan, A. Kendall, R. Cipolla, and S. Member, "SegNet : A Deep Convolutional Encoder-Decoder Architecture for Image Segmentation," vol. 39, no. 12, pp. 2481–2495, 2017.

[41] Y. Li, J. Xiao, Y. Chen, and L. Jiao, "Neurocomputing Evolving deep convolutional neural networks by quantum b ehave d particle swarm optimization with binary encoding for image classification," vol. 362, pp. 156–165, 2019, doi: 10.1016/j.neucom.2019.07.026.

[42] R. Mohakud and R. Dash, "Designing a grey wolf optimization based hyper-parameter optimized convolutional neural network classifier for skin cancer detection," vol. 34, pp. 6280–6291, 2022.

[43] B. Zhou and B. Arandian, "An Improved CNN Architecture to Diagnose Skin Cancer in Dermoscopic Images Based on Wildebeest Herd Optimization Algorithm," Comput. Intell. Neurosci., vol. 2021, 2021, doi: 10.1155/2021/7567870.

# Instance Segmentation Method based on R2SC-Yolact++

Liqun Ma[1], Chuang Cai[2], Haonan Xie[3], Xuanxuan Fan[4], Zhijian Qu[5], Chongguang Ren[6*]

School of Computer Science and Technology, Shandong University of Technology, Zibo 255000, China[1, 2, 3, 4, 5, 6]
Jinan Inspur Data Technology Co., Ltd, Jinan 250000, China[6]

*Abstract*—To address the problems of missed detection, segmentation error and poor target edge segmentation in the instance segmentation model, a R2SC-Yolact++ instance segmentation approach based on the improved Yolact++ is proposed. Firstly, the backbone network adopts Res2Net which introduces spatial attention mechanism (SAM) to improve the problem of segmentation error by better extracting feature information; then, high-quality masks are obtained by fusing the detail information of the shallow feature P2 as the input to the prototype mask branch; finally, the problem of missed detection was solved by introducing Cluster-NMS in order to improve the accuracy of the detection boxes. In order to illustrate the effectiveness of the improved model, experiments were conducted on two publicly available datasets, the COCO and CVPPP datasets. The experimental results show that the accuracy on the COCO dataset is 1.1% higher than the original model. And the accuracy on the CVPPP dataset is 1.7% better than before the improvement, which is better than other mainstream instance segmentation algorithms such as Mask RCNN. Finally, the improved model is applied to the insulator dataset, which can segment the shed of insulator accurately.

*Keywords—Instance segmentation; Yolact++; Res2net; Cluster-NMS; insulator dataset*

## I. INTRODUCTION

With the rapid development of deep learning, our life is also moving towards automation, such as automatic driving and automatic picking, etc. The first problem that needs to be solved for these tasks is to recognize the category as well as the location of the target, and the current deep learning based methods mainly include object detection and image segmentation. Object detection can only detect the category as well as the location of the target, cannot identify the specific and accurate outline of the target. Deep learning-based image segmentation methods include semantic segmentation and instance segmentation. Semantic segmentation can only classify the targets in an image into different categories, and different instances belonging to the same category cannot be distinguished. Instance segmentation can identify both the class and the exact contour position of different instances. Therefore, it is important to study how to accurately segment different instances using instance segmentation.

Instance segmentation is an important and difficult branch of computer vision, and its task is to identify the target contour location and classify it at pixel level to get the segmentation mask of different instances. The existing instance segmentation algorithms are mainly classified into single-stage and two-stage instance segmentation methods. The two-stage instance

segmentation method has the advantage of higher accuracy, but the model is complex and slow. Mask RCNN [1], proposed in 2017, is one of the most commonly used detection-based methods, using the two-step idea of Faster RCNN [2], to which a branch of prediction segmentation masks is added. PANet [3] made improvements to Mask RCNN by introducing bottom-up paths and expanding the feature pyramid network, which improved the accuracy, but also slowed down a lot. The advantage of single-stage segmentation methods is that the model is simple and fast, but the accuracy is relatively low. Typical single-stage methods include the anchor frame-based method YOLACT proposed by Bolya et al. [4], which divides the instance segmentation task into two parallel branches and achieves real-time instance segmentation for the first time, but the accuracy was poor, and it was later improved by proposing YOLACT++ [5], which significantly improved the segmentation accuracy by adding deformable convolution and presetting more anchor frames using mask rescoring. The method CondInst [6] was proposed in 2020 to solve instance segmentation from a new perspective, using dynamic masks and not relying on ROI operations, achieving higher accuracy and being faster. Since the accuracy of the anchor frame-based method depends greatly on the set anchor frame hyper-parameters, a segmentation method without anchor frames is proposed afterwards. SOLO [7] proposed in 2020 uses the location information of instances for instance classification. It is to divide the different instances by assigning the instances to different channels based on the fact that each instance has a different center point and size. The accuracy was further improved with the later improved SOLO V2 [8]. In recent years, with the amazing results achieved by Transformer in natural language processing, it has also been applied to instance segmentation with good results [9, 10].

Although there has been a great development in instance segmentation, there is still a lot of room for development of existing models in terms of accuracy improvement. The problems such as segmentation errors as well as poor target edge segmentation due to insufficient extraction of image information, and missed detection due to inaccuracy of prediction boxes, all contribute to the low accuracy of segmentation. To address the above problems, this paper proposes an instance segmentation method based on the improved Yolact++. The method can better extract features, effectively improve the problems of missed detection and segmentation errors, and enhance the accuracy of instance segmentation. The main contributions of this paper are summarized as follows:

- The R2SC-Yolact++ algorithm is proposed to address the problems of segmentation error and missed detection in Yolact++.

- The model introduces Res2Net for the segmentation error problem and embeds a spatial attention mechanism for better feature extraction, and fuses shallow features with P3 as input to the protonet branch to solve the problem of poor segmentation edges, and finally Cluster-NMS was introduced to solve the problem of missed detection caused by the suppression of too many detection boxes.

- Validating and comparing the segmentation performance of the proposed model on two publicly available datasets and a homemade insulator dataset.

- The paper is organized as follows: Section II presents the related works for segmentation, Section III describes the proposed R2SC-Yolact++ method, Section IV analyzes and discusses the experimental results, and Section V concludes the paper.

## II. RELATED WORK

Early traditional image segmentation mainly used the digital image processing technology; the main methods include segmentation methods based on region, edge detection, etc. OSTU finds the threshold value as the segmentation value to distinguish the foreground from the background based on the gray scale distribution of the gray scale map using inter-class variance method. Canny [11] edge detection algorithm performs edge detection by finding the optimal edge pixels and is the most commonly used segmentation method. These methods is generally based on the brightness and color of the pixels in the image, as well as the degree of variation in the pixel values, so they are susceptible to segmentation errors due to uneven illumination, noise, and other factors.

With the development of deep learning, segmentation methods based on deep learning are proposed, which are divided into semantic segmentation and instance segmentation. Semantic segmentation is a pixel-level classification of images to distinguish different classes of targets. The beginning of semantic segmentation was the use of full convolutional networks [12] (FCN) for classification, after which semantic segmentation developed rapidly. U-Net [13] was proposed for medical segmentation in 2015, which uses an encoder-decoder structure to extract features and fuse shallow features with deep semantic information to fully use image contextual information for accurate segmentation of medical images, but has the problem of slow segmentation speed. The DeepLab series [14-17] proposed afterwards have continuously improved segmentation accuracy and efficiency by introducing atrous convolution to reduce model parameters, proposing ASPP to solve the problem of target segmentation at different scales, and introducing decoder structure to optimize the problem of poor segmentation edge accuracy. SegFormer [18] proposed a hierarchical Transformer encoder structure by combining semantic segmentation with Transformer, using overlapping patches to ensure the local continuity of features, while using deep convolution to replace position encoding to convey position information and obtain a high-quality segmentation map. But semantic segmentation has a problem in application, it cannot distinguish different instances belonging to the same class, and many applications need to mark each different instance, so later proposed instance segmentation. However, how to improve the accuracy of instance segmentation and accurately segment the target is an urgent problem.

Existing instance segmentation algorithms are continuously improved from all angles to enhance the accuracy of segmentation. For the problem of segmentation errors and missed segmentation, many studies ResNeXt [19], Res2Net [20], etc. are solved from the perspective of better feature extraction to improve the feature expression ability of the backbone network. The use of attention mechanisms [21-23] has also been proposed to make the network focus on important features and suppress unnecessary features. The accuracy of the detection boxes also affects the accuracy of the segmentation, so many scholars have devoted to obtaining more accurate detection boxes by using more comprehensively computed loss functions DIoU, CIoU [24], etc., or by using more appropriate non-maximum suppression to obtain detection boxes that are more in line with the target. Nowadays the algorithms also commonly have the problem of poor target edge segmentation, many solutions have been proposed for this problem, such as adding an additional loss to the segmentation boundary of the network output, and Xuecheng Li [25] proposed an edge loss function so as to improve the accuracy of the segmentation edge. Improving the segmentation of edges by increasing the resolution of the input image as well as the extracted feature maps is also a relatively straightforward approach, but this adds a significant amount of computation.

The Yolact++ instance segmentation model chosen in this paper, which is simple and realizes real-time segmentation, has been applied in many fields and improvements have been made to address the problems so that they can better segment the objects. Yajun Li in [26] proposed an extended network based on Yolact that can simultaneously detect fruit bundles as well as segment fruit stalks, which can accurately and quickly identify the pose of fruit bunches to support successful picking by picking robots. Based on Yolact++, RTLSeg is proposed to segment the railroad track [27], the feature enhancement module is proposed to improve the feature extraction and characterization ability of the model, PaFPN is used to enhance the interaction of information, as well as the location awareness is added to the Protonet module to obtain a high-quality prototype mask. These improvements effectively enhance the segmentation accuracy of the railroad track and can accurately and efficiently segment the railroad track line components. Zhenni Shang [28] used Yolact, which introduces the SE attention mechanism to enhance feature expression and FRelu activation function, for efficient segmentation of protozoa in microscopic images.

## III. MODEL OVERVIEW

### A. Principle of Yolact++

ResNet50 with deformable convolution was introduced as the backbone network to extract features from the input image, and total of five different scales of feature maps, C1-C5, were obtained. For efficiency, Yolact++ uses only C3-C5 for feature fusion through FPN to obtain P3-P5, and downsamples from

P5 to obtain P6 and P7. Then after two parallel branches, one branch is the detection branch with inputs P3-P7, anchor frames with aspect ratios [1, 1/2, 2, 1/3, 3] are generated and classified, regressed, mask coefficients predicted, and non-maximum suppression (Fast NMS) is applied to get the final instance prediction boxes. The other branch is the prototype mask branch, which uses P3 as input and obtains k mask maps

corresponding to different regions after convolution and upsample. The prototype mask maps and the mask coefficients are linearly combined by matrix multiplication to obtain the instance masks, which are intercepted by the prediction boxes, and the final mask segmentation maps are obtained by threshold processing and binarization. The structure of the Yolact++ model is shown in Fig. 1.
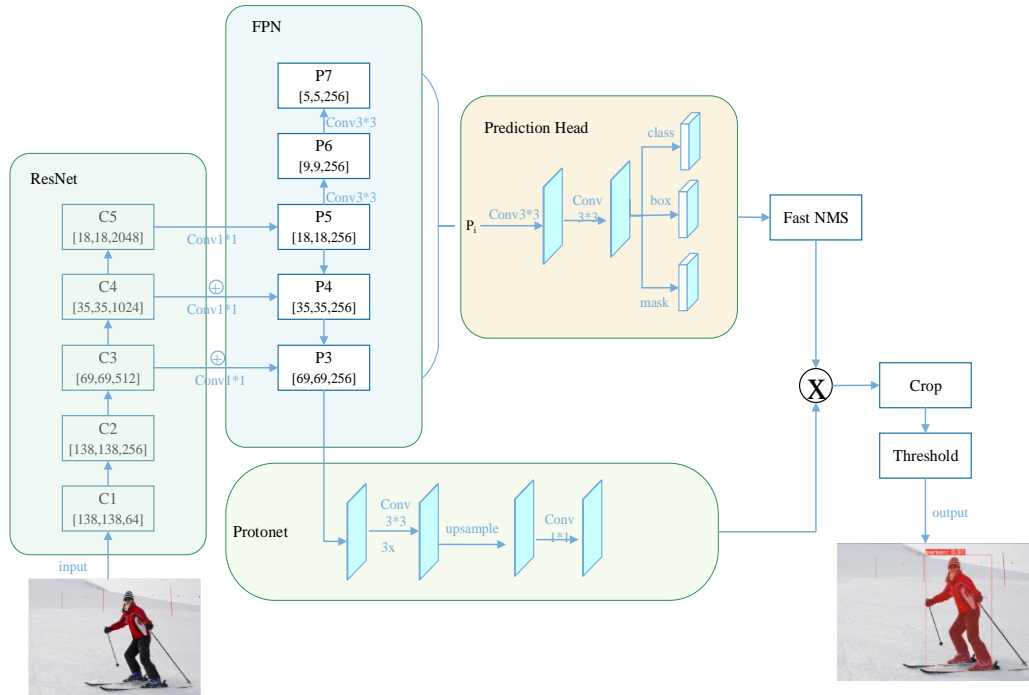


Fig. 1.    Structure of the Yolact++ model.

### B.  Improved Backbone

The quality of feature maps for feature extraction directly affects the subsequent detection and segmentation, so the backbone network is improved to address the problem of inadequate feature extraction. The Res2Net module is used to replace the bottleneck structure of ResNet to represent multi-scale features at a finer granularity, and to increase the receptive field of each network layer to extract more detailed information about the edges as well as the overall information about the target. ResNet bottleneck structure requires layer-by-layer 3×3 convolution for multi-scale feature extraction. Res2Net is realized by a set of (s layered) 3×3 convolutions to do multiple scales within a block, using similar connections to residual networks for connectivity, which can output features with more number of different scales and enhance the expressive power of the network. This is achieved by averaging the feature map obtained after 1×1 convolution into four sub-feature maps with the same number of channels (n/4), the third sub-feature map $x_3$ is summed with the new sub-feature map $y_2$ obtained from the second sub-feature map $x_2$ after 3×3 convolution as an input to the corresponding convolution to obtain the feature map, and so on. In order to fuse the information of different scales, the four feature maps obtained are merged and the final feature map is output after 1×1 convolution. Res2Net is beneficial for extracting global and local information by segmenting and re-splicing the feature

maps for combined use. In order to make the network more focused on the target region and reduce the interference from the background, the spatial attention mechanism is added after the 1×1 convolution and before the residual connection, as shown in Fig. 2.
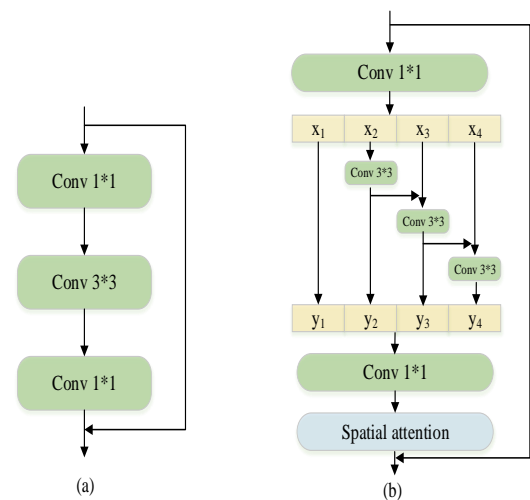


Fig. 2.    Comparison of original Resnet bottleneck block and improved res2net module: (a) Resnet bottleneck; (b) Improved res2net module.

Pixels at different locations in an image have different importance, with pixels close to the target being more important and those far from the target more likely to be in the background. The role of spatial attention mechanisms is to enable the network to focus on the "where" part of the information, focusing on important features and suppressing unnecessary features. The specific implementation of the spatial attention mechanism is shown in Fig. 3. Firstly, average pooling and maximum pooling are performed on the feature maps along the channel direction to aggregate the channel information of the feature maps, two H×W×1 feature maps are obtained for stacking, and a feature map is obtained after a 7×7 convolution, and then the spatial attention weight is obtained by the sigmoid function. Finally, the original feature map is used to multiply the spatial weights and output the feature map with positional importance.

### C. Prototype Mask Branch Improvement

The higher the resolution of the image, the more detailed information it contains, but the more computationally intensive it is. Yolact++ only uses C3-C5 for feature fusion through FPN in order to raise the speed of computation, and uses the deepest feature map P3 as the input to the Protonet branch. Because of the lack of utilization of shallow features, a lot of detailed information is lost, resulting in poor quality of the resulting prototype masks and poor segmentation of the edges. So in order to get high quality prototype masks, we fuse shallow feature maps as input. Firstly, P2 is obtained by fusing features with FPN, and fusing the low-level information requires convolution of P2 to complete the downsampling. Then P3 is added with the downsampled P2 to get the fused features as the input to the prototype mask branch, and the prototype mask maps are obtained after the protonet branch. The realization process is shown in Fig. 4.
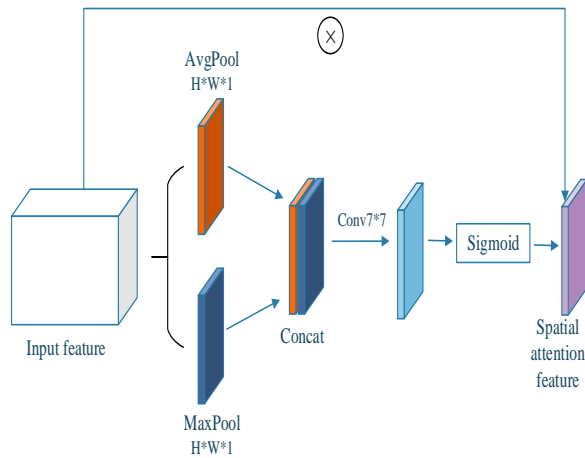


Fig. 3. Spatial attention module.
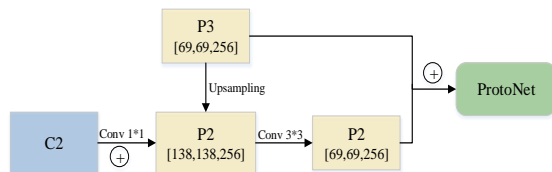


Fig. 4. Structure of the fused shallow feature map.

### D. Improvement of Non-Maximum Suppression

The segmentation accuracy of the anchor-based instance segmentation method is affected to some extent by the detection performance. In Yolact++, the segmentation performance is improved by increasing the number of frames to detect difficult and different scale targets, so a large number of redundant boxes are generated, and the model uses Fast NMS instead of Traditional NMS in order to improve the detection speed. It obtains the thresholded binarized one-dimensional vector $b=\{b_i\}_{1\times N}$, $b_i \in \{0, 1\}$ by computing the IoU matrix $X$ for every two boxes, performing upper triangulation, and solving for the maximum value of each column to directly remove the detection boxes with high overlap. However, this leads to the suppression of too many detection frames, and detection boxes with high overlap but belonging to different instances are deleted, leading to the occurrence of missed detection, which reduces the detection accuracy and thus affects the accuracy of segmentation. Therefore, this paper proposes the use of Cluster-NMS instead of Fast NMS, which can make up for the problem of accuracy degradation caused by Fast NMS while ensuring the detection speed. Instead of suppressing the prediction box directly after obtaining the vector $b$, Cluster-NMS introduces two matrices with the following equations. First, $b$ is expanded into a symmetric matrix with the same diagonal elements as $b$, and then the matrix $C$ is obtained by left-multiplying the matrix $X$. The purpose is to omit the effect of the suppressed boxes from the previous iteration on the other boxes. And keep performing the above iterations for $C$. The end of the iteration is indicated when the $b$ obtained from two consecutive iterations is unchanged. By introducing Cluster-NMS, the problem of missed target detection leading to missed segmentation can be improved and the segmentation accuracy of the model can be improved while maintaining high efficiency.

$$A^t = \mathrm{diag}\left(b^{t-1}\right) \tag{1}$$

$$C^t = A^t \times X \tag{2}$$

### IV. EXPERIMENTAL METHODS AND ANALYSIS OF RESULTS

### A. Experimental Environment and Parameter Description

All experiments in this paper are based on Windows 10 operating system, hardware system is Intel Core i5-10400F, graphics card is NVIDIA Geforce RTX 2070 SUPER and running memory is 8G. GPU processing six images at a time in ablation experiments, and the size of images are uniformly processed to 550×550. Initial momentum is set to 0.9, learning rate is 0.001, weight decay is 0.0005.

### B. Datasets

To validate the effectiveness of the improved model, this paper uses two publicly available datasets for training and testing, and the models were applied to the insulator dataset produced by ourselves to segment the shed of insulator. The MS COCO dataset is a large image dataset developed and maintained by Microsoft and is the most commonly used open standard dataset. In this paper, we conduct comparative experiments of instance segmentation algorithms using the COCO 2017 dataset, which contains 80 categories of life. The

CVPPP dataset is a plant image dataset that provides tobacco and Arabidopsis raw images as well as labeled images to segment plant leaves. The dataset is divided into a total of four sub-datasets, A1-A4, and A5 is the sum of the four sub-datasets, including 810 images of the training set. In order to facilitate subsequent processing and comparison of results, the dataset labels were processed into COCO format. In this paper, ablation experiment are conducted on the CVPPP dataset to verify the effectiveness of the improved module, and the segmentation effect before and after the model improvement is tested on the COCO dataset. And comparison experiments are conducted on CVPPP dataset to compare and analyze the segmentation results of different models.

We need to segment the shed of insulator to find the shed location, so we made insulator dataset and segmented it using improved algorithm. Most of the collected insulator pictures are composite insulators. In addition, in order to ensure the diversity of insulators and improve the generalization ability of the model, insulator images of different types and environments are collected from the Internet. The images were labeled using LabelMe, and a total of 581 images were labeled and randomly augmented by flipping, panning, adding noise, and changing brightness to 2316 images with 19204 instances. The dataset was divided into a training set of 1481, a validation set of 371, and a test set of 464. To facilitate subsequent processing, the dataset is converted to COCO dataset format. According to the configuration of the experimental environment and to ensure the validity of the experimental comparison, the image size was resized to 550×550 in all experiments.

### C. Evaluation Metrics

All experiments in this paper were evaluated and analyzed using COCO evaluation metrics, mainly showing the mAP, $AP_{50}$, $AP_S$, $AP_M$, $AP_L$. Average accuracy AP is the mean value of accuracy at an IoU of 0.5-0.9, an interval of 0.05, and a recall of 0-1 under a category, calculated as shown in Eq. (3), and the area under a two-dimensional curve plotted with recall as the horizontal axis and precision as the vertical axis. MAP is the mean value of AP for all categories, $AP_{50}$ for accuracy at IoU=0.5. S, M, and L are distinguished according to the size of the area of the examples, and the accuracy is obtained separately.

$$AP = \int_0^1 P(\mathrm{r})\mathrm{d}r \tag{3}$$

### D. Ablation Experiments

In order to quantitatively analyze the impact of the introduction of Res2Net in Yolact++ combined with attention to the backbone network, feature fusion, and improved non-maximal value suppression on the segmentation performance, this paper uses the above methods in combination with Yolact++ and ablation experiments on the CVPPP dataset. All experiments on the CVPP dataset were iterated 150,000 times. The structure of each model in the ablation experiment and the results are shown in Table I. Res2Net indicates the backbone module of Res2Net combined with the attention mechanism, feature fusion indicates that P2 is fused with P3 as the input of the prototype mask, and "√" indicates the introduction of the

corresponding module. The experimental results quantify the effects of these methods on plant leaf segmentation performance.

TABLE I. COMPARISON OF ABLATION EXPERIMENTAL RESULTS OF CVPPP DATASET

| Experiment | Res2net | Feature Fusion | Cluster-NMS | mAP |
|------------|---------|----------------|-------------|------|
| 1 | - | - | - | 65.6 |
| 2 | √ | - | - | 66.7 |
| 3 | √ | √ | - | 66.9 |
| 4 | √ | - | √ | 67.2 |
| 5 | √ | √ | √ | 67.3 |

Experiment 1 shows the segmentation results of the baseline model on the CVPPP dataset. In order to harmonize the evaluation criteria, the paper does not use the evaluation metrics specified in the CVPPP dataset, but instead uses the COCO evaluation metrics. Experiment 2 was the improved Res2net combined with Yolact++, and the mAP was improved by 1.1%, comparing with Experiment 1 shows that the introduction of Res2net is more beneficial to extract global as well as local features, and the addition of spatial attention can make the network focus more on the target part, thus improving the segmentation accuracy. Experiment 3 represents the fusion of shallow features with the original Protonet input feature P3 based on Experiment 2 to increase the feature detail information and get a higher quality prototype mask, which results in more accurate edge segmentation. Experiment 4 is the introduction of Cluster-NMS on the basis of Experiment 2. Because Fast NMS is prone to treat two frames that are close to each other but belong to two different similar instances as two overlapping frames of one instance, one of the frames will be suppressed for deletion, and thus there will be a problem of missed detection. And the leaves of a plant are similar in shape and close together, so it is more likely to have the problem of missed detection. Compared with Experiment 2, mAP is improved, indicating that Cluster-NMS can solve the problem of Fast NMS suppressing too many boxes and leading to missed detection, thus improving the segmentation accuracy. Experiment 5 shows the segmentation results of our model, which combines the above method with Yolact++, and the experimental results show that our model improves the segmentation accuracy of plant leaves by 1.7% compared to the accuracy before improvement.

Fig. 5 visualizes the variation of the total loss value over the training set, which serves as a measure of the error between the predicted results and the true annotation, with smaller losses indicating more accurate predictions and better segmentation performance of the model. As shown in the figure, the loss values of the baseline model Yolact++ as well as the improved model are visualized in the figure. The loss values of the two models leveled off after about 110,000 iterations, with the pre-improvement model eventually stabilizing at about 1.41 and the post-improvement model loss values eventually stabilizing at about 1.35. In general, the loss value curves of the improved model are below those of the baseline model. As well as Fig. 6 reflects the mAP comparison on the validation set before and after the model improvement,

both of which demonstrate that the segmentation performance of the improved model is better than that of the baseline model.
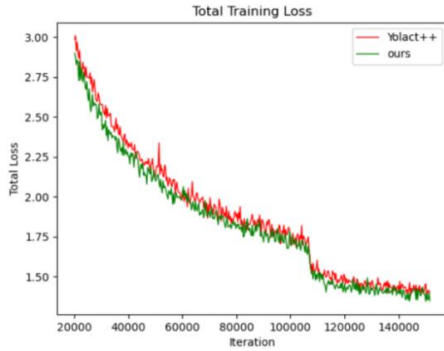


Fig. 5.   Loss value curve.
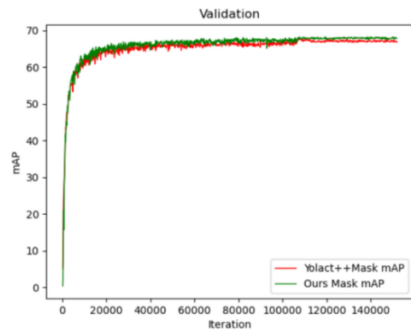


Fig. 6.   CVPPP validation set mAP plot.

Fig. 7 visualizes the leaf segmentation results before and after the model improvement. Column (a) of the figure shows the original image of the plant leaf, and the red boxes in the figure show where the results are significantly better after the improvement. Columns (b) and (d) show the leaf segmentation results for the model before and after the improvement,

respectively, and column (c) shows the leaf segmentation results obtained from Experiment 2 in the ablation experiment. There are two shaded leaves segmented into one leaf in the red box of the first image, and there are cases where the edge portion is not accurately segmented. After feature extraction by Res2net combined with spatial attention, the features are better extracted and the edges are segmented accurately. In column (d) all leaves are accurately segmented. Comparing columns (b) and (c) of the second figure illustrates that the improved backbone network can solve the problem of segmentation error, but there is still the problem of missed segmentation, comparing column (c) and (d) shows that Cluster-NMS can solve the problem of missed segmentation. The missed detections in the third figure are also well resolved, indicating that our model has better segmentation than Yolact++.

Table II shows the segmentation performance of the model before and after improvement on the MS COCO val2017. The experiment set batch_size to 4 and trained 54 epochs. Because the background of the COCO dataset is more complex and the number and size of targets differ significantly from the CVPPP dataset, resulting in a lower mAP of the mask than the CVPPP dataset. And due to the problem of different computer configurations, the experimental results are somewhat different from those of the published papers. The table shows that the accuracy of the model is 1.1% higher after the model improvement than before the improvement, and the mAP of the instances of different sizes is improved.

TABLE II.        SEGMENTATION RESULTS ON COCO DATASET

| Model | Backbone | mAP | $AP_{50}$ | $AP_S$ | $AP_M$ | $AP_L$ |
|-------|----------|-----|-----------|--------|--------|--------|
| Yolact++ | Resnet50 | 33.1 | 51.8 | 11.6 | 35.5 | 54.3 |
| Ours | Resnet50 | 34.2 | 52.8 | 12.1 | 36.9 | 56.1 |
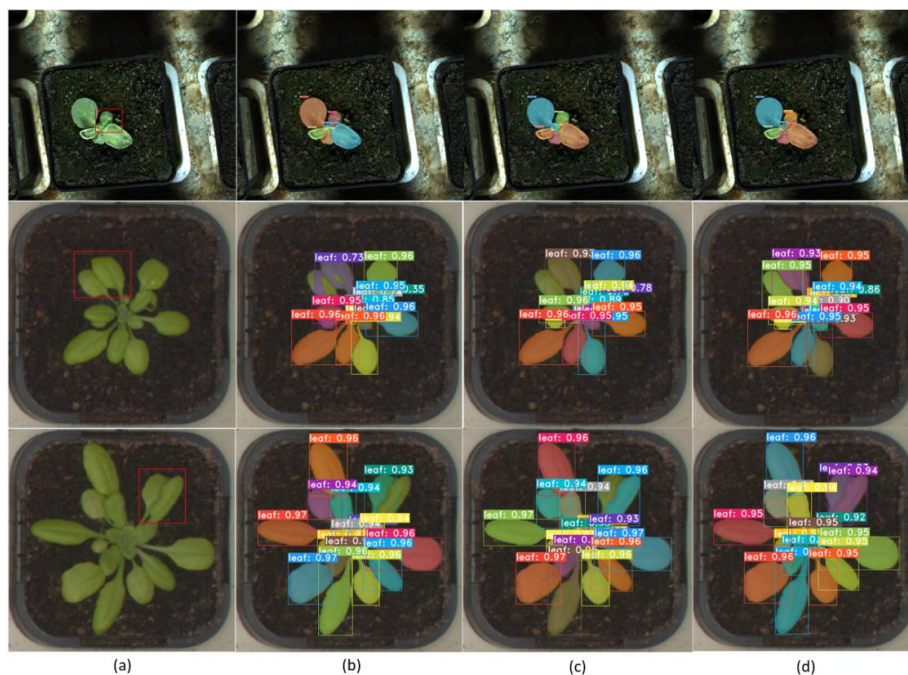


Fig. 7.   Visualization of leaf segmentation results.

### E. *Comparison of Different Models*

To further validate the effectiveness of the improved model, we trained the CVPPP dataset and insulator dataset using several commonly used segmentation models, and tested and compared the segmentation results, as shown in Table III and Table IV. The tables show the mAP of the two-stage segmentation model Mask RCNN, the single-stage models CondInst, Yolact++, the segmentation models without anchor boxes SOLO, SOLO V2, and the improved algorithm of this paper on two datasets, as well as the $AP_{50}$ and the accuracy of these models for different sized targets ($AP_S$, $AP_M$, $AP_L$). From the experimental results in Table III, the segmentation results of SOLO are poor because the leaf size of a plant is relatively similar and the leaves have small intervals or even overlap each other, so there will be multiple leaves of similar size appearing in the same grid, resulting in poor segmentation of leaves. Other models perform well on the CVPPP dataset, but all of them also have the problem of segmentation error and missed detection. The improved algorithm makes improvements to address the above problems, and the segmentation of plant leaves is better than other models.

Insulators play an important role in the power system, and damage to insulators can affect the entire line. They are an important concern in power system inspections, so it is important to ensure the cleanliness and integrity of insulators. First of all, it is necessary to identify the shed of insulator and find the exact location of the shed. Due to the uneven illumination and shadows caused by the insulator usage scenario, the shed of insulator cannot be accurately segmented by the traditional image segmentation method. So how to quickly and accurately segment a single shed is a problem that needs to be solved urgently, in this paper, we use several instance segmentation algorithms to train insulator datasets and segment the shed of insulator, the results are shown in Table IV, and the segmentation results were visualized as shown in Fig. 8.

TABLE III.    COMPARISON OF SEGMENTATION RESULTS OF MAINSTREAM MODELS FOR CVPPP DATASET

| Model | Backbone | mAP | $AP_{50}$ | $AP_S$ | $AP_M$ | $AP_L$ |
|---|---|---|---|---|---|---|
| Mask RCNN | Resnet50 | 62.7 | 89.2 | 44.9 | 79.9 | 71.7 |
| CondInst | Resnet50 | 63.5 | 92.3 | 43.3 | 82.5 | 86.8 |
| SOLO | Resnet50 | 59.2 | 83.0 | 33.3 | 79.7 | 79.3 |
| SOLO V2 | Resnet50 | 62.2 | 83.3 | 36.3 | 82.3 | 83.7 |
| Yolact++ | Resnet50 | 65.6 | 88.9 | 45.1 | 81.5 | 73.7 |
| Ours | Resnet50 | 67.3 | 91.0 | 45.9 | 83.3 | 79.9 |

TABLE IV.    COMPARISON OF THE RESULTS OF DIFFERENT MODELS FOR INSULATOR DATASET

| Model | Backbone | mAP | $AP_{50}$ | $AP_S$ | $AP_M$ | $AP_L$ |
|---|---|---|---|---|---|---|
| Mask RCNN | Resnet50 | 36.3 | 83.0 | 24.3 | 32.0 | 41.0 |
| CondInst | Resnet50 | 26.1 | 75.3 | 11.3 | 19.0 | 34.3 |
| SOLO | Resnet50 | 37.2 | 87.8 | 18.5 | 32.2 | 42.7 |
| SOLO V2 | Resnet50 | 40.4 | 92.3 | 19.2 | 34.7 | 46.8 |
| Yolact++ | Resnet50 | 40.2 | 78.5 | 24.7 | 33.5 | 47.6 |
| Ours | Resnet50 | 41.7 | 82.3 | 24.5 | 34.3 | 49.9 |
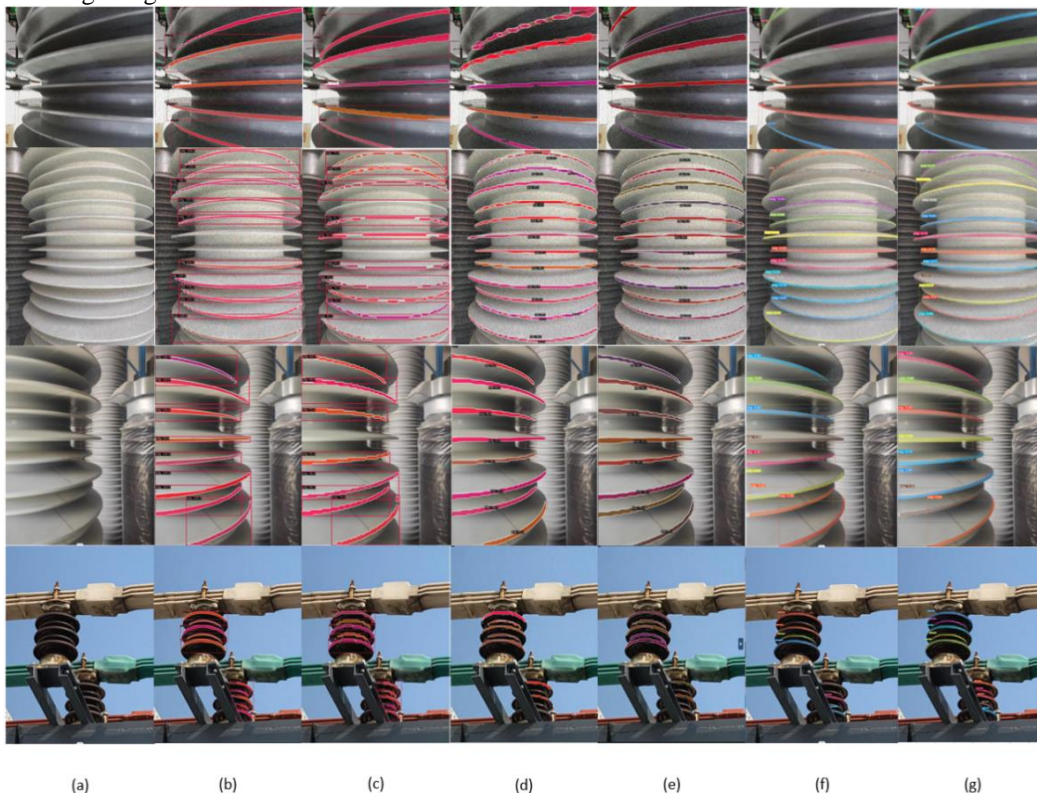


Fig. 8.    Comparison of segmentation results of mainstream models: (a) Original image; (b) Mask RCNN segmentation results; (c) CondInst segmentation results; (d) SOLO segmentation results;  (e) SOLO V2 segmentation results; (f) Yolact++ segmentation results; (g) Our model segmentation results.

The insulator dataset is used to train the above mainstream example segmentation model and this paper's algorithm, respectively, and the trained model is used to verify the detection and segmentation effect of the shed of insulator. The training results are compared in Table IV. The experimental results show that CondInst has the worst segmentation effect. Mask RCNN, SOLO performs slightly worse on the insulator dataset, mAP is slightly lower than the baseline model, and SOLO V2 and Yolact++ segmented well. The masks of Yolact++ use all the information of the picture space without repooling, which does not cause the performance loss of the mask, the segmentation accuracy for large target objects is significantly higher than other methods, and most of the insulator datasets are large targets, so the baseline model Yolact++ has a higher mAP than other models. The improved model made improvements to the problems of the baseline model, and the accuracy was improved by 1.5% over the baseline model, with the best segmentation results.

Fig. 8 visualizes the shed of insulator segmentation results of the mainstream instance segmentation models. In general, all the models in Table IV have the problems of missed detection and poor segmentation of shed edges. Mask RCNN has obvious missed detection. The most problematic segmentation result of SOLO is the segmentation error, which divides one shed into multiple sheds. SOLO V2 performs better than SOLO, and the problem of segmentation error is well solved, but there is also the problem of poor segmentation edge. The segmentation results of our improved model are the best, and the problems of missed detection as well as poor segmentation edges that occur in the baseline model are improved to segment the shed of insulator more accurately.

### F. Discussion

In this paper, segmentation performance is validated and compared on two publicly available datasets as well as a homemade insulator dataset. In order to more easily compare and illustrate the segmentation effects of the analytical models on different datasets, the article uniformly uses the COCO evaluation metrics. Experimental results show that our model achieves better segmentation results on all three datasets. The improvement is greater on the CVPPP and insulator datasets, which have only one category, similar and densely distributed targets, and the algorithm's backbone and NMS method improvements both lead to improved segmentation performance for these targets. The experimental results of the three datasets can also illustrate that the model has a greater improvement in the segmentation of large targets. However, the model focuses on improving accuracy and does not focus on model complexity as well as speed issues, and subsequent studies will further optimize the model. And the collected insulator images have the problem of a single type and scene, and the insulator segmentation dataset needs to be enriched subsequently.

## V. CONCLUSION

In this paper, Yolact++ is used as a baseline model to improve the accuracy of the model by aiming at the problems of segmentation error, missed segmentation and low accuracy of edge segmentation. Firstly, the use of Res2net which incorporates a spatial attention mechanism as a backbone enables the backbone network to better extract global and local features, acquire target information with clear boundaries, and improve the problem of segmentation errors. Second, the shallow features P2 and P3 are fused and input to the Protonet branch to obtain a high-quality prototype mask map that does not depend on a particular instance. Finally, the introduction of Cluster-NMS improves the problem of missed detection due to the suppression of too many detected boxes by iteratively and gradually eliminating the influence of the boxes with too much overlap on the other boxes, which improves the detection accuracy and segmentation accuracy. Training and testing on the public datasets COCO and CVPPP datasets are performed to verify the effectiveness of the improved model, and the average accuracy of the mask is 1.1% higher on the COCO dataset, and the accuracy on the CVPPP dataset is 1.7% higher than before the improvement. The improved model is applied to the insulator dataset labeled by itself to segment the shed of insulator, and the experimental results show that a more accurate the shed of insulator segmentation is achieved.

### REFERENCES

[1] He K M, Gkioxari G, DOLLÁR P, Girshick R, "Mask R-CNN," Proceedings of the 2017 IEEE International Conference on Computer Vision, Venice, Oct 22-29, 2017, Washington: IEEE Computer Society, pp. 2980-2988, 2017.

[2] Ren S Q, HE K M, Girshick R B, Sun J, "Faster R-CNN:towards real-time object detection with region proposal networks," Proceedings of the Annual Conference on Neural Information Processing Systems 2015, Montreal, Dec 7-12,2015, Red Hook: Curran Associates, pp. 91-99, 2015.

[3] LIU S, QI L, QIN H, et al., "Path aggregation network for instance segmentation," Proceedings of the 2018 IEEE Conference on Computer Vision and Pattern Recognition, Salt Lake City, Jun 18-22, 2018, Washington: IEEE Computer Society, pp. 8759-8768, 2018.

[4] Bolya D, Zhou C, Xiao F, Lee Y J, "YOLACT:real-time instance segmentation," Proceedings of the 2019 IEEE/CVF International Conference on Computer Vision, Piscataway: IEEE, pp. 9156-9165, 2019.

[5] Bolya D, Zhou C, Xiao F, Lee Y J, "YOLACT++:better real-time instance segmentation," IEEE Transactions on Pattern Analysis and Machine Intelligence, 2020, 44(2):1108-1121.

[6] Tian Z, Shen C, Chen H, "Conditional convolutions for instance segmentation," Computer Vision – ECCV 2020. Berlin, German:Springer, pp. 282-298, 2020.

[7] Wang X, Kong T, Shen C, Jiang Y, Li L, "SOLO:segmenting objects by locations," LNCS 12363:Proceedings of the 16th European Conference on Computer Vision, Cham:Springer, pp. 649-665, 2020.

[8] Wang X, Zhang R, Kong T, Li L, Shen C, "SOLOv2: Dynamic and fast instance segmentation," Advances in Neural Information Processing Systems, 2020, 33: 17721-17732.

[9] Guo R, Niu D, Qu L, Li Z, "SOTR:Segmenting Objects with Transformers," 2021 IEEE/CVF Conference on Computer Vision and Pattern Recognition, USA:IEEE, pp. 7157-7166, 2021.

[10] Li F, Zhang H, Xu H, et al., "Mask DINO: Towards A Unified Transformer-based Framework for Object Detection and Segmentation." Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition, 2023:3041-3050.

[11] Canny, J., A Computational Approach To Edge Detection, IEEE Trans. Pattern Analysis and Machine Intelligence, 8: 679-714, 1986.

[12] Long J, Shelhamer E, Darrell T, "Fully convolutional networks for semantic segmentation," proceedings of the Proceedings of the IEEE conference on computer vision and pattern recognition, 2015.

[13] Ronneberger O, Fischer P, Brox T, "U-net:Convolutional networks for biomedical image segmentation," proceedings of the International Conference on Medical image computing and computer-assisted intervention, 2015. Springer.

[14] Chen L-C, Papandreou G, Kokkinos I, K Murphy，AL Yuille, "Semantic image segmentation with deep convolutional nets and fully connected crfs," Computer Science, 2014(4):357-361.

[15] Chen L-C, Papandreou G, Kokkinos I, K Murphy，AL Yuille, "Deeplab:Semantic image segmentation with deep convolutional nets, atrous convolution, and fully connected crfs," IEEE transactions on pattern analysis and machine intelligence, 2017, 40(4):834-48.

[16] Chen L-C, Papandreou G, Schroff F, Adam H, "Rethinking atrous convolution for semantic image segmentation," Computer Vision and Pattern Recognition, 2017, 17(6): 1-14.

[17] Chen L-C, Zhu Y, Papandreou G, Schroff F, Adam H, "Encoder-decoder with atrous separable convolution for semantic image segmentation," proceedings of the Proceedings of the European conference on computer vision(ECCV), 2018.

[18] Xie E, Wang W, Yu Z, et al., "SegFormer:Simple and efficient design for semantic segmentation with transformers," Advances in Neural Information Processing Systems, 2021, 34:12077-90.

[19] Xie S, R Girshick, P Dollár, Tu Z, He K, "Aggregated Residual Transformations for Deep Neural Networks," 2017 IEEE Conference on Computer Vision and Pattern Recognition(CVPR), pp. 5987-5995, 2017.

[20] Gao S, Cheng M, Zhao K, et al., "Res2net:A new multi-scale backbone architecture," IEEE Transactions on Pattern Analysis and Machine Intelligence, 2019, 43(2):652-662.

[21] Hu J, Shen L, Sun G, "Squeeze-and-excitation networks," Proceedings of the IEEE conference on computer vision and pattern recognition, pp. 7132-7141, 2018.

[22] Woo S, Park J, Lee J Y, Kweon S, "Cbam: Convolutional block attention module," Proceedings of the European con-ference on computer vision (ECCV), pp. 3-19, 2018.

[23] Zhang H, Zu K, Lu J, Zou Y, Meng D, "EPSANet: An efficient pyramid squeeze attention block on convolutional neural network," Proceedings of the Asian Conference on Computer Vision, Macau, Dec 4, pp. 1161-1177, 2022.

[24] Zheng Z, Wang P, Liu W, et al., "Distance-IoU loss:Faster and better learning for bounding box regression," US:AAAI, 2020, 34(7):12993-13000.

[25] Li X, Zheng Y, Zang M, Jiao W, "Wavelet transform and edge loss-based three-stage segmentation model for retinal vessel," Biomedical Signal Processing and Control, vol. 86, 105355, 2023.

[26] Li Y, Feng Q, Liu C, et al., "MTA-YOLACT: Multitask-aware network on fruit bunch identification for cherry tomato robotic harvesting," European Journal of Agronomy, vol. 146, 126812, 2023.

[27] Wei D, Wei X, Tang Q, et al., "RTLSeg: A novel multi-component inspection network for railway track line based on instance segmentation," Engineering Applications of Artificial Intelligence, vol. 119, 105822, 2023.

[28] Shang Z, Wang X, Jiang Y, Li Z, Ning J, "Identifying rumen protozoa in microscopic images of ruminant with improved YOLACT instance segmentation," Biosystems Engineering, vol. 215, pp. 156-169, 2022.

# Blockchain-Enabled Security Framework for Enhancing IoT Networks: A Two-Layer Approach

Hosny H. Abo Emira[1], Ahmed A. Elngar[2], Mohammed Kayed[3]

Faculty of Computer Science, Nahda University (NUB), Beni-Suef City, Egypt [1]
Faculty of Computers and Artificial Intelligence, Beni-Suef University, Beni-Suef City, Egypt [2, 3]

*Abstract*—**The increasing proliferation of Internet of Things (IoT) nodes poses significant security challenges for their network's communication. Blockchain technology, with its decentralized and distributed nature, has the potential to address these security concerns within IoT networks. LEACH (Low Energy Adaptive Clustering Hierarchy) algorithm and blockchain technology enhance IoT network security, enabling energy-efficient data management and transaction integrity, enhancing network lifespan and protection. This paper presents a security model that combines the LEACH algorithm and blockchain technology to improve IoT networks' security. The LEACH algorithm forms clusters of IoT devices, with a designated cluster head (CH) responsible for data aggregation and forwarding. Our model incorporates blockchain technology's core principles and cryptographic foundations, providing additional security measures. It consists of two main layers: the LEACH clustering-based routing protocol, which forms clusters and layers, and a blockchain simulator module. The LEACH algorithm enhances energy consumption, enables efficient data management within clusters, and ensures the integrity, transparency, and immutability of transactions. Our model is implemented on a simulator, allowing for experimentation and modification to evaluate the performance and effectiveness of the security enhanced IoT network model. Our results demonstrate the effectiveness of the proposed enhanced LEACH algorithm compared to previous algorithms, in which the last node died after 1868 transactions. As well as the results of the pro-posed framework, which record 0.058% of the state rate and 2.75 Throughput. Simulation results are validated with respect to previous algorithms, and it obtained higher accuracy compared to them.**

*Keywords—Internet of Things (IoT); Blockchain (BC); LEACH; clustering; authentication; security*

## I. INTRODUCTION

Internet of Things (IoT) security faces numerous challenges in ensuring the protection of connected devices and the data they generate [1]. The sheer scale and heterogeneity of IoT systems, along with limited computational resources and varying security measures, make it challenging to implement standardized security protocols [2]. Challenges also arise from the massive volume of data generated, the lack of comprehensive security regulations, and the complexity of managing security updates [3]. To address these challenges, a holistic approach is required.

One potential solution to various IoT security challenges is blockchain technology. Blockchain's decentralized and immutable ledger ensures data integrity, transparency and prevents tampering [4]. Cryptographic algorithms enable secure authentication and identity management, limiting access to trusted devices. The distributed nature of blockchain eliminates single points of failure, enhancing system resilience [5]. Additionally, blockchain facilitates secure and private data sharing through encryption and selective disclosure, maintaining confidentiality. Smart contracts automate trust and enforce predefined rules, reducing the risk of errors or malicious actions [6]. By leveraging blockchain, IoT systems can benefit from enhanced security, data integrity, privacy, and resilience.

To further enhance IoT security, the LEACH (Low-Energy Adaptive Clustering Hierarchy) algorithm can be integrated with blockchain [7]. Originally designed for wireless sensor networks, LEACH focuses on energy optimization and efficient data management through clustering. By combining LEACH with blockchain, the security and trustworthiness of IoT networks can be enhanced [8]. The algorithm ensures an even distribution of energy load among devices, extending their lifespan and reducing the risk of vulnerabilities [9]. The blockchain provides a decentralized and immutable ledger for securely recording and verifying IoT transactions, ensuring data integrity and transparency. Together, the LEACH algorithm and blockchain technology offer a comprehensive approach to IoT security, addressing energy efficiency, data integrity, and trust, ultimately strengthening the overall security of IoT networks [10].

In this paper, we present a two-layer BC security model that aims to protect IoT networks while simplifying the implementation process. Our proposed model leverages the inherent features of blockchain technology, such as immutability, transparency, and decentralization, to enhance the security of IoT communication. By incorporating blockchain into the architecture, we establish a secure and tamper-proof environment for IoT devices. Additionally, we propose an enhanced LEACH algorithm, powered by fuzzy logic, for efficient data aggregation in IoT-enabled applications, with a specific focus on maximizing network lifetime. Our proposed algorithm optimizes the energy consumption and communication strategies of IoT devices, prolonging the overall lifespan of the network. Through extensive simulations, we demonstrate the effectiveness of our proposed enhanced LEACH algorithm compared to similar works, highlighting its superior performance in terms of network lifetime and energy efficiency.

To support the analysis and evaluation of diverse blockchain systems and their deployments, we introduce a

comprehensive framework and software tool. This framework enables the construction and simulation of discrete-event dynamic system models for blockchain systems. At the core of the framework lies the Base Model, which encompasses fundamental model constructs shared among various blockchain systems and is organized into abstract layers such as network and consensus. The Base Model provides adaptability and extensibility, allowing for the incorporation of specific system or deployment details. Furthermore, we provide a detailed description of the implementation of the simulator within the proposed framework, along with its application to the Ethereum blockchain. To validate the simulation results, we compare our findings to real-life systems and past research reported in previous studies to ensure their dependability and correctness.

In summary, the main contribution of this paper is threefold. First, we present a two-layer Blockchain Security model that safeguards IoT networks and simplifies their implementation. Second, we propose an enhanced LEACH algorithm that maximizes network lifetime through efficient data aggregation techniques. Finally, we utilized a comprehensive framework and software tool for constructing and simulating blockchain system models, facilitating analysis and evaluation. Collectively, these contributions provide a solid foundation for enhancing the security, reliability, and efficiency of IoT networks through the integration of blockchain technology.

The paper is organized as follows in the following sections: The second section discusses the related work. The third section examines the Proposed Methodology. The fourth section describes the model's implementation. The fifth section discusses the experimental results and validation. The last section summarizes the paper's contribution.

## II. RELATED WORK

Recently, there has been a growing interest in integrating blockchain technology into IoT. However, very few researchers were interested in how BCs can help in IoT device authentication requirements. In this section, we review the existing literature that focuses on integrating blockchain into IoT ecosystems, highlighting the scarcity of works that successfully address security requirements in this integration.

presents a summary of proposed solution, technology, advantages, and disadvantages of related works.

Yanhui, Liu, et al. [11] focused on the security of user identification and privacy in IoT. By protecting the user's identity and privacy, it becomes impossible for an attacker to link the acquired data with the actual identity of the user, thereby ensuring the safety of the user. To enhance the reliability of the system, the study employs the features of blockchain, which are immutable and incorruptible. The proposed approach records transaction details of user information using Hyperledger and conceals the actual identity of the user using the ring signature method. To generate the necessary parameters for the signature, the system employs a key generator to provide the system with public parameters and ring membership information. Finally, the study also includes an accountability mechanism to punish any attackers who seek

to squander system resources by disclosing the user's identity and therefore denying them access to the system.

Ourad, et al. [12] suggests a blockchain-based approach for secure communication and authentication of IoT devices. The solution exploits the inherent characteristics of blockchain while integrating with pre-existing authentication techniques. The study also includes an accountability mechanism to punish any attackers who seek to squander system resources by disclosing the user's true identity and therefore denying them access to the system.

TABLE I. SUMMARY OF RELATED WORK

| Ref No. | Proposed Solution | Technology | Advantages | Disadvantages |
|---|---|---|---|---|
| [11] | Blockchain to protect user identity in IoT | Hyperledger, Ring Signature, Aggregated Signature | Identity privacy, Reliability | Waste system resources |
| [12] | Blockchain-based authentication for IoT devices | Blockchain, Authentication | Accountability, Tamper-proof logs | Resource constraints |
| [13] | Improved blockchain-based authentication protocol | Ethereum, Security, Anonymity | Secure access, Formal verification | Computational cost |
| [14] | IoT blockchain architecture for identity authentication | BCoT, Gateway, Device recognition | Distributed ledger, Feasibility | Device modification |
| [15, 16] | Multi-layer blockchain security model for 5G-enabled IoT | Hyperledger Fabric, Clustering, Evolutionary Computation | Security, Network authentication | Latency, Throughput |
| [17] | Secure data dissemination using AI and blockchain | AI-based intrusion detection system, blockchain, smart contracts, Interplanetary File System (IPFS) | Efficient and secure data transmission, resistance to attacks | Cost and complexity of implementing blockchain technology |
| [18] | Blockchain and DL integrated framework | Digital Twin (DT), Smart Contracts, LSTMSAE, MHSA-based BiGRU | Enhances communication security and data privacy | High computational power requirement, Potential for network congestion |

Yavari, Mostafa, et al. [13] reveals that a unique authentication system for the administration of IoT device information based on blockchain is vulnerable to security risks such as secret disclosure, replay, traceability, and reuse attacks, all with a probability of success and a constant complexity of 1. The study also includes an improved blockchain-based authentication protocol (IBCbAP) that provides safe access management as well as anonymity. The JavaScript programming language and the Ethereum local blockchain were used to create the IBCbAP. Additionally, the study

verifies the security of IBCbAP through informal and formal analysis using the Scyther tool.

L Gong, et al. [14] proposes a mechanism and creates an IoT blockchain architecture for storing device identity information in a decentralized ledger. The research also suggests a Blockchain of Things (BCoT) Gateway, which streamlines the recording of authentication transactions in a blockchain network without requiring any changes to existing device hardware or applications. In addition, a new device recognition model that is well-suited for blockchain-based identity authentication is provided, utilizing a novel feature selection mechanism for device traffic flow. Finally, the study develops the BCoT Sentry framework as a reference model for the suggested strategy.

Honar Pajooh, Houshyar, et al. [15, 16] proposed a Multi-layer Blockchain Security model that can safeguard IoT networks and be implemented in a simple manner. The model uses clustering to make the multi-layer structure easier to manage. The IoT network is partitioned into K-unknown clusters using approaches that combine Simulated Annealing and Genetic Algorithms. The chosen cluster chiefs are in charge of local authentication and permission. The suggested concept is built on the open source Hyperledger Fabric Blockchain technology. Base stations securely communicate information with one another using a global blockchain architecture.

Kumar, Prabhat, et al. [17] presents a safe way of data distribution based on AI and blockchain technologies. The technology gathers data from healthcare sensors put around the patient's home and sends it to neighboring edge devices. The acquired data is filtered by an AI-based intrusion detection system positioned at the network's edge. The blockchain is then used to create a secure health monitoring network, in which regular or filtered transactions are forwarded to centralized cloud servers and approved via a smart contract-enabled consensus method. Validated transactions are saved on the cloud's distributed Interplanetary File System (IPFS), and the returned transaction hash is saved on the blockchain ledger at the edge devices, allowing for speedier data sharing.

Kumar, Prabhat, et al. [18] provide a decentralized data processing and learning framework in the Industrial Internet of Things (IIoT) network that combines blockchain technology and Deep Learning (DL). A unique Decision Tree (DT) paradigm is used in the framework to provide a virtual environment for modelling and reproducing IIoT security-critical processes. In the proposed blockchain-based data transmission architecture, smart contracts are employed to ensure data integrity and authenticity. Furthermore, the authors developed a DL approach that uses an Intrusion Detection System (IDS) to evaluate blockchain data. The DL scheme employs the Long Short-Term Memory-Sparse Autoencoder (LSTMSAE) technique to learn spatial-temporal representations, as well as the proposed Multi-Head Self-Attention (MHSA)-based Bidirectional Gated Recurrent Unit (BiGRU) algorithm to learn long-distance features and accurately detect attacks.

Al Ahmed, Mahmoud Tayseer, et al. [19] proposes the Authentication-Chains protocol, a decentralized, distributed blockchain-based authentication mechanism for IoT. The protocol clusters nodes and creates a unique authentication blockchain for each cluster. These cluster chains are linked by another blockchain. The proposed consensus mechanism is based on proof of identity verification to address the limited processing capabilities of IoT devices. The security performance of the protocol is analyzed and tested using cryptographic protocol verifier software, and a test bed based on the Raspberry Pi network is shown to validate the protocol's performance.

A significant study gap in the body of current literature is evident, with few studies devoted to examining the relationship between blockchain technology and IoT device authentication requirements. Although there is a rising interest in incorporating blockchain technology into IoT ecosystems, recent endeavours have primarily concentrated on security considerations or other use cases. It has been largely neglected to address the unique difficulty of guaranteeing strong device authentication inside this integration. The examined publications provide insightful information about several facets of blockchain's potential in the context of the Internet of Things, including how it might improve user privacy, secure communication, access control, and data distribution. Still, there isn't much of a focus on IoT device authentication standards.

## III. Proposed Methodology

The proposed model aims to enhance the security of IoT networks by combining the LEACH algorithm and blockchain technology. In this section, we will introduce how The LEACH algorithm optimizes energy consumption and enables efficient data management within clusters, while blockchain technology ensures the integrity, transparency, and immutability of transactions. The LEACH algorithm is utilized to form clusters of IoT devices, with a designated cluster head (CH) responsible for data aggregation and forwarding within each cluster. By employing a randomized rotation of CHs, the LEACH algorithm ensures an even distribution of energy load among devices, thereby extending the network's lifespan. The primary objective of the randomized rotation is to achieve an even distribution of the energy load among devices in the network, which in turn helps to prolong the network's lifespan.

In our proposed model, we have integrated the core principles and cryptographic foundations of blockchain technology to provide additional security measures. Fig. 1 illustrates the system architecture, showcasing the structure of the model and the interaction between its components.

The proposed model consists of two main layers. Firstly, the LEACH clustering-based routing protocol forms clusters and layers within the IoT network. Unsupervised hybrid clustering algorithms are employed to create multiple clusters, with each cluster associated with a robust CH. Within each cluster, IoT devices and nodes undergo authentication and authorization processes, ensuring privacy and security.

Fig. 1.   Proposed model.

privacy and security inside each cluster, devices are authenticated and authorized to access the network through the use of local authorization and authentication services.

Fig. 2 shows the clustering approach for the IoT network. The clustering is done with the utilization of the LEACH algorithm. LEACH is a clustering-based routing protocol specifically designed for wireless sensor networks with limited energy resources. LEACH helps in reducing the latency and overhead in IoT systems by minimizing communication distances among IoT objects and selected cluster heads. With clustering, fewer nodes require long-distance transmissions to the base station (BS) nodes, resulting in reduced total power consumption and improved network coverage.
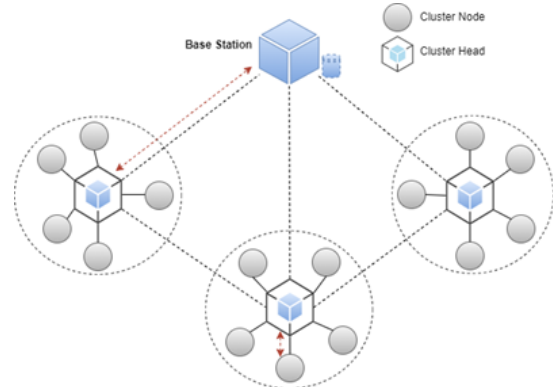


Fig. 2.   IoT network clustering scheme.

Our technique, which employs the LEACH clustering algorithm, also aids in maximizing the application efficiency of BC (Blockchain) technology by minimizing deployment complexity. The CH nodes control the whole network, which is separated into non-overlapping clusters, while other cluster members interface with the CH nodes for data transfer.

The goal is to accomplish clustering by deploying the LEACH algorithm throughout the network. In the suggested approach, critical network characteristics such as distance, network coverage, energy, and load are handled as node clustering factors.

Our technique presents LEACH-based clustering, which avoids uniform distribution of nodes and clusters in order to model the heterogeneous character of the IoT network. The overall number of clusters and the number of nodes in each cluster are not predetermined. As a result, the overall network's lifespan rises, but energy dissipation within CH nodes becomes more uniform.

*B. Blockchain Simulator*

In this section, we present the Base Model that forms the foundation of the Blockchain Simulator. The simulator's purpose is to replicate many sorts of blockchain systems while also allowing for the installation of specific application enhancements as required. We begin by explaining the Blockchain Simulator's design principles and aims, emphasizing generality, flexibility, and accessibility. Following that, we go over the architecture layer by layer, beginning at the network layer and ending with the Consensus Layer. We

Secondly, the model incorporates a blockchain simulator module, which serves as the engine of the simulator. This module comprises four categories: event, scheduler, statistic, and main. It works on three steps: transaction creation and appending to the transaction pool, block generation where transactions are executed and added to the blockchain, and block reception where the new block becomes a permanent part of the blockchain ledger. The transaction pool is also updated accordingly.

By combining the LEACH algorithm and blockchain technology, our proposed model aims to provide enhanced security for IoT networks. The LEACH algorithm optimizes energy consumption and enables efficient data management within clusters, while blockchain technology ensures the integrity, transparency, and immutability of transactions. This integration enhances the overall security and trustworthiness of IoT systems.

*A. Cluster Head Selection Algorithim*

This level includes Internet of Things objects, nodes, and devices, as well as network elements in charge of communication, network processes, and protocols. Unsupervised hybrid clustering methods divide the IoT network into numerous clusters and layers. Each group is assigned a strong device known as the CH (Cluster Head). IoT devices and nodes are geographically dispersed. To ensure

define the primary functional components (entities) inside each layer and characterize the tasks or activities they carry out.

*1) Principles of design:* The Base Model's design is governed by the Blockchain Simulator's key aims, which are as follows:

*a) Generality:* The Blockchain Simulator will be relevant to a broad range of blockchain systems, setups, and architectural queries.

*b) Flexibility:* It should be easy for designers or analysts to manipulate the Blockchain Simulator to explore different aspects of blockchain systems.

*c) Accessibility:* Regardless of the goals, the Blockchain Simulator should remain user-friendly, both for conducting simulation studies and for extending its capabilities.

Designing a tool like the Blockchain Simulator involves striking a balance between generality and extensibility, while simultaneously ensuring simplicity. The Base Model plays a crucial role in achieving this balance, as it determines the level of generality supported by the model class and the ease with which new models can be built. The Base Model is also converted into software modules, it affects the ease with which the Blockchain Simulator may be extended to create more thorough representations of certain blockchain processes.

The Blockchain Simulator caters to the essential components of all blockchains (nodes, transactions, blocks, and incentives). The Base Model defines the level of generality in the model class supported by the Blockchain Simulator, as well as the ease with which new models can be constructed. By representing these building blocks in software modules, the Base Model also influences the extensibility of the Blockchain Simulator, enabling the provision of more detailed models for specific blockchain processes.

*2) Network layer:* The Blockchain Simulator's Network Layer is made up of two components: The underlying Broadcast protocol and Node. The Node entity oversees keeping system state variables like the transactions pool and the blockchain ledger up to date. The Broadcast protocol specifies how data items such as Blocks and Transactions are broadcast over the network.

The Node object includes both the Blockchain ledger and the Transactions pool entities. These entities are kept and updated in real time by each node. Nodes are represented as objects, each having its own unique ID, balance, local ledger, and transactions pool. When fresh transactions and blocks arrive, the transactions pool and local ledger are represented as expandable array lists. All blockchain implementations have these traits. These traits, however, may be broadened by introducing additional ones.

The Broadcast protocol entity is used for information entity dissemination, which may be properly simulated by taking network configurations, node geographical distribution, and node connection into consideration. It can also be abstracted by considering only a time delay for information propagation among nodes. The simulator is simplified by concealing unneeded features by abstracting the broadcast protocol, resulting in a decrease in network setup settings such as the broadcast protocol, geographical distribution of nodes, and the number of connections per node. The simulator improves efficiency and usability by making the propagation delay the only parameter that may be changed.

*3) Consensus layer:* The purpose of the Consensus Layer is to describe the rules that nodes must follow in order to agree on the state of the block-chain. This layer consists of four components: a transaction, a block, a transactions pool, and a blockchain ledger. The Block entity is reliant on the Blockchain ledger entity, which is dependent on the Transaction entity. As a result, the blockchain ledger is composed of blocks, which are composed of transactions. Because every produced transaction is placed in the Transactions pool, it is dependent on the Transaction entity. These four entities are managed by the Node entity.

Within the Consensus Layer, the entities perform a range of activities or actions. One example of such activity is the creation of blocks and transactions. Fig. 3 depicts the flow of these operations, which occur continuously since transactions and blocks are regularly brought to the network. Fig. 3 depicts the process for the consensus operations within the Blockchain Simulator's Base Model.

*a) Transaction:* Transactions are essential components of all blockchain platforms and play an important role in updating the state of the blockchain. A new transaction affects the transaction pool by being added to the network when it is introduced.

We employ two modelling approaches for transactions: full and light. The full technique tracks each individual transaction in the system, allowing for the analysis of transaction latency. While this technique closely resembles real-world blockchain transactions, it demands substantial computing resources and simulation time due to tracking each transaction separately. On the other hand, the light technique focuses on studying the throughput of blockchain systems, disregarding transaction confirmation time within the system. Irrespective of the chosen modelling technique, we represent transactions as objects with various attributes for instance transaction ID, timestamp, contents, size, submitter, and recipient. These attributes are generally shared across most blockchains.

In the full modelling technique, using an array list abstraction, we establish an independent transactions pool for each node in the whole modelling method. Each participating node in the network receives a transaction when it is generated by a node. When a transaction is received, the receiving node adds it to its own pool. This method includes three different activities: transaction creation, transaction propagation, and transaction adding.
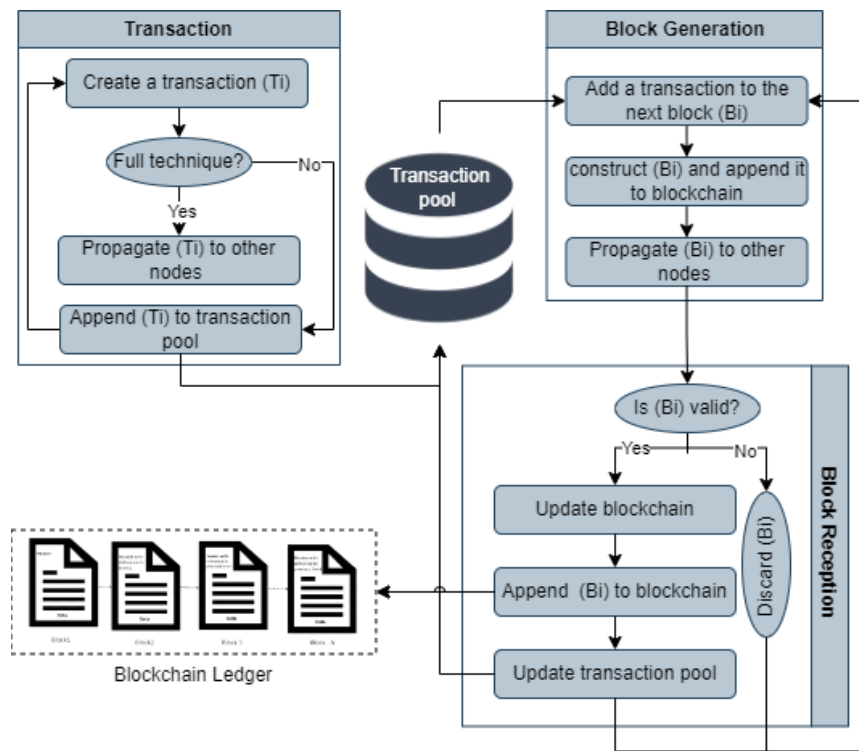
Fig. 3. Workflow of the consensus operations within the blockchain simulator's base model.

In the light modelling technique, we employ a single shared transactions pool among all network nodes. This method offers a simplified approach to modelling transactions by excluding the propagation process and continuous pool updates by nodes. Consequently, the light technique enhances simulation efficiency and speed. However, because individual transactions are not recorded, it cannot give insights into transaction slowness. Nonetheless, it is useful for collecting throughput metrics in blockchain systems. Then Before the mining process, we construct a number of transactions (N) and then append them to the common pool. Miners may utilize this pool to choose numerous transactions to include in their next block. In most cases, the number of transactions (N) should be sufficient for one or two blocks. When a miner creates a successful block, the pool is reset, and a new batch of transactions is added for the following block.

Both modelling methods can be employed in the Blockchain Simulator, granting users the flexibility to choose the method that aligns best with their specific needs. For instance, if the primary focus is on throughput analysis, the full technique may not be necessary due to its significant extension of simulation runtime.

*b) Block:* Blocks are crucial elements of blockchain systems, which are made up of transactions. When a new block is added, it updates the transactions pool as well as the blockchain ledger. The block's transactions are removed from the pool, and the freshly created block is added to the ledger to update it. Blocks are represented as objects in our models, with different features like depth, block ID, previous block ID, date, size, miner ID, and transactions. The block ID acts as a unique identifier, whereas the block depth reveals its location inside the node's blockchain. The miner ID identifies the node that created the block. As its content, each block provides a list of transactions. These characteristics are prevalent across several blockchain systems.

In the consensus layer, we represent blocks using two basic processes: block creation and block receiving. Block construction refers to the actions taken by a miner to generate and attach a block to the blockchain ledger. These activities include completing the transactions included inside the block, constructing the block, adding it to the local blockchain, and disseminating the block to other nodes in the network. Block reception, on the other side, is concerned with how nodes update their blockchain ledgers in response to new blocks. When a valid block arrives, a recipient node performs three actions: it updates the local blockchain, appends the block to the local blockchain, and updates the transactions pool.

A node validates the authenticity of a new block when it receives it. A block is deemed valid if it was appropriately produced and includes correctly performed transactions. Our attention is drawn to block depth as a measure of validity. To be considered as legitimate, the received block must be deeper than the previous block in the ledger. Any block with a low depth that deviates from the existing blockchain is rejected and deleted. If the received block meets the depth requirement, the recipient node takes three steps: it updates its local blockchain if necessary to align with the received block, it adds the block to its local copy of the blockchain, and it refreshes the transactions pool by removing transactions already executed in the block.

*c) Transactions pool and blockchain ledger:* The Blockchain Ledger and Transactions Pool are key components of blockchain systems that reflect their status. The transactions pool is updated anytime a new transaction or block enters the network, but the blockchain ledger is only updated when a block is received. Because each node has its own copy of the pool and ledger, The blockchain network's nodes oversee maintaining and updating both.

Due to network propagation delays, nodes may briefly retain distinct viewpoints of the blockchain ledger when forks occur. To remedy this, the consensus layer creates rules for nodes to follow to resolve forks and obtain consensus. Popular blockchain systems such as Ethereum and Bitcoin use the longest-chain rule. This rule states that nodes must update their ledgers anytime. They are given a block that adds to a chain that is longer than their own. This method guarantees that nodes retain a synchronized view of the blockchain ledger, encouraging participant consensus.

## IV. PROPOSED MODEL IMPLEMENTATION

This section contains, the Network Clustering algorithm is introduced, which aims to optimize parameters by iteratively updating them based on an objective function. The algorithm starts with an initial parameter set and iterates through a specified number of iterations. It utilizes a stochastic search process, where the mean guides the search while a random vector introduces randomness. The algorithm aims to find the parameter set that minimizes the objective function. Additionally, the proposed simulator implementation using Python is discussed, including modules such as the Simulator Module, Configuration Module, and the Ethereum module, which is divided into the Network Module and Consensus Module. The simulator enables the customization of parameters and allows users to analyze the performance and behavior of blockchain systems.
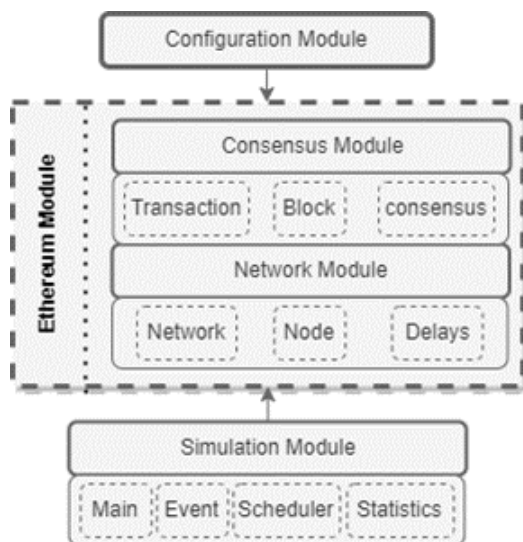


Fig. 4. Proposed implementation modules.

### A. Network Clustering

The algorithm represents an optimization process as shown in Algorithm 1 that aims to find the best parameters for a given objective function E. It starts with an initial parameter set to the value P0 and a standard deviation S. The number of iterations K determines how many times the algorithm will repeat.

The algorithm iterates from $i = 0$ to $i \leq K$, updating the parameters Pi and the mean Mi at each iteration. At each iteration, a random vector Ni is created with a normal distribution, using the mean Mi and standard deviation S.

If the objective function value $E(Pi + Ni)$ is lower than $E(Pi)$, indicating an improvement, the parameters are updated as follows:

- $Pi+1 = Pi + Ni$, meaning the new parameters are obtained by adding the random vector Ni to the current parameters Pi.

- $Mi+1 = \alpha Mi + \beta Ni$, where $\alpha$ and $\beta$ are constants used to adjust the influence of the mean and the random vector on the update. They can be tuned to control the step size and exploration-exploitation balance.

If the objective function value $E(Pi \cdot Ni)$ is lower than $E(Pi)$, indicating another type of improvement, the parameters are updated as follows:

- $Pi+1 = Pi \cdot Ni$, meaning the new parameters are obtained by element-wise multiplication between the current parameters Pi and the random vector Ni.

- $Mi+1 = \gamma Mi \cdot Ni$, where $\gamma$ is a constant used to control the influence of the mean and the random vector on the update.

If neither of the above conditions is satisfied, indicating no improvement, the parameters remain the same:

- $Pi+1 = Pi$

- $Mi+1 = \delta Mi$, where $\delta$ is a constant used to control the influence of the mean on the update.

After the iterations are completed, the optimized parameters PK are returned.

Algorithm 1. Optimization of Function Parameters

| **Algorithm 1:** Optimization of Function Parameters |
| --- |
| Given: **P0** for the initial parameters, **S** for the standard deviation, and **K** for the number of iterations |
| *Returns: PK, the optimised parameters* |
| **Initialize Mi** = 0. |
| **for** $i = 0$; $i \leq K$; $i = i + 1$ repeat |
| Make a normal distribution random vector **Ni** with a mean **Mi** and standard deviation **S**. |
|   **if** $E(Pi + Ni) < E(Pi)$ **then** |
|     Pi+1 = Pi + Ni |
|     Mi+1 = α Mi + β Ni |
|   **else if** $E(Pi\ Ni) < E(Pi)$ **then** |
|     Pi+1 = Pi Ni |
|     Mi+1 = γ Mi Ni |
|   **else** |
|     Pi+1 = Pi |
|     Mi+1 = δ Mi |
|   **end** |
| **end** |

This algorithm employs a stochastic search process that explores the parameter space by iteratively updating the parameters based on the objective function's evaluations. The mean Mi helps guide the search process, while the random vector Ni introduces randomness and exploration. The algorithm aims to find the parameter set that minimizes the objective function E.

### B. Blockchain Implementation

The proposed simulator implementation is presented by using Python 3.9 with Intel Core i7-2670QM CPU @ 2.20 GHz processor and 8 GB memory. Fig. 4 depicts the key modules. The Simulator Module implements the simulator's engine and is divided into four categories: event, scheduler, statistic, and main. The configuration module enhances the simulation module by allowing the user to customize the simulation model and experiments. The Ethereum module is used to put the suggested Blockchain Simulation into action. It is separated into the following layers: Network and Consensus Modules.

*1) Simulation module:* The event class specifies the structure of simulation events. A block-level event contains four attributes: node ID, time, type , and block. Provides event preparation at two extraction levels, Examines Blocks (Bi) as Event (E), and Examines Transactions (T) as Event (E). The attribute type specifies how the event should be handled, specifically whether the current event should generate a new block or receive a previously created block. The node ID and timestamp are allocated to the node responsible for handling the event and its time management. The block attribute holds the essential information required for the occurrence of the block.

The scheduler class handles future event scheduling and recording in the queue. The array list queue acts as a storage method for handling future events inside the simulation. It undergoes continuous updates during the simulation process, accommodating the insertion of new events and the removal of existing ones. To illustrate, when an event triggers the creation of a block, the scheduler class acts by scheduling deny reception events for other nodes. These deny reception events are designed to prevent other nodes from receiving the newly created block. By scheduling such events, the simulation ensures that the block remains exclusive to the node that created it, thereby controlling its distribution within the network. It also organizes a new block generation event, in which a miner is chosen to propose and build a new block on top of the previous block.

The Main class creates the environment and then instructs the Scheduler class to schedule some basic events in order to start the simulator. The initial setup involves generating transactions and creating the first block, also known as the genesis block. Following that, the simulation advances by executing events sequentially, one after the other, until either the queue is empty, or the preset simulation time limit is achieved. Throughout this process, the Statistics class plays a crucial role. It collects and maintains the results generated during the simulation, allowing for the calculation of various statistics related to the final output. This includes analyzing

block-related data, such as the number of blocks included in the ledger. By utilizing the Statistics class, the simulation can provide valuable insights and metrics that help evaluate the performance and behavior of the system being simulated.

*2) Configuration module:* This module's goal is to serve as the primary user interface, allowing users to customize parameters relating to nodes, blocks, transactions, consensus, and simulation setups. It allows for the modification of the simulation environment and improves user engagement. Table II shows the input settings that were set before starting the simulator. The duration between blocks, the number of nodes, the number of transactions to be created each second, as well as other characteristics, may all be specified. Furthermore, the simulator disables transactions that are not interesting. This can only be accomplished by setting the option has Trans to "False" and not altering the simulator code. Furthermore, it simulates the transactions by employing an appropriate approach.

TABLE II. INPUT PARAMETERS CONFIGURED BEFORE RUNNING THE SIMULATOR

| Type | Parameter | Description |
|---|---|---|
| Blocks | B interval | The average time to produce a block in seconds |
| | B size | Block size in Megabyte (MB) |
| | B delay | Block propagation delay time in seconds |
| | Tn | The frequency with which transactions can be created |
| | T delay | Transactions propagation delay in seconds |
| | T size | Transaction size in MB |
| Nodes | Nn | The total number of network nodes |
| Simulation | Sim time | Duration of the simulation |
| | Runs | Number of simulations runs |

*3) Ethereum in proposed simulator:* This section discusses the development of simulation classes that reflect the Ethereum Model utilizing the previously described two levels.

Network Module: This module is implemented in two classes: the node class and the network class. The simulator uses node class to define the structure of nodes. Every node is assigned a distinct ID and has an associated balance, implemented as an individual object for each node. The local BC and the transactions pool are modelled by assigning two array lists. When the full transaction approach is used, each node just keeps a transactions pool. Otherwise, shared a common pool by all the nodes. To propagate both blocks and transactions among nodes, the network latency is implemented using network class. In the configuration module, the user of the simulator can configure the time delay in which it is implemented as the latency. As a result, the broadcast protocol, which governs how information entities (such as Blocks and Transactions) are distributed across networks, may be implemented.

Consensus Module: is divided into three classes: Transactions, Block, and Consensus. Every transaction is represented by an object with the following properties: ID, submitter ID, receiver ID, timestamp, value, and size. There are numerous actions to be performed by the entities inside this layer, which may be explained as follows:

- Transactions class:

Create transaction (Ti),

Propagate Ti to other Nodes (Ni)  Ti $\longrightarrow$ Ni,

Append Ti to Transaction Pool (TP) Ni $\longrightarrow$ TP: [Ti].

- The second class is Block Generation that have three actions:

Execute transactions to the next Bi TP $\longrightarrow$ Bi: [Ti],

Construct Bi and append it to local BC (LBC)

Bi $\longrightarrow$ LBC,

Propagate Bi to all Ni LBC $\longrightarrow$ Ni: [Bi].

- After generating new Bi and stored in LBC the class named block reception check validation of block if it not valid will return it to Block Generation class if it valid:

Update LBC Ni $\longrightarrow$ LBC,

Append Bi to local BC (LBC) Ni $\longrightarrow$ LBC: [Bi],

Update TP Ni $\longrightarrow$ TP: [Bi].

In the setup module, the end user can select transaction sizes as fixed integers or random values derived from a wide range of distributions, including the accelerating distribution. Transaction modelling approaches are also used in this class. Each block is represented as an object that has information like depth, ID, previous ID, timestamp, size, miner ID, and transactions. This class also handles block creation and reception. The consensus class is responsible for implementing the consensus algorithm as well as the process of selecting leaders for the generation and insertion of new blocks into the ledger.

## V. EXPERIMENTAL RESULTS AND DISCUSSION

This section contains the network environment is simulated to evaluate the performance of the proposed clustering algorithm. The simulation consists of one hundred random generated nodes distributed in a 2-D network. The clustering techniques are applied in MATLAB 2018a, which offers a dependable environment and makes it simple to compare the outcomes. The simulation parameters include simulation area dimensions, number of nodes, initial energy of each node, and packet size. The simulation results demonstrate the effectiveness of the proposed clustering model and the algorithm's ability to reduce total network energy. Fig. 6 shows the operational nodes per transmission, operational nodes per round, and energy consumed per transmission, respectively. Additionally, we compare the performance of different protocols in terms of the number of nodes, energy consumption, first node dies, and last node dies. The results

highlight the superiority of the proposed Enhanced LEACH protocol in terms of network lifespan. Furthermore, we compare the network lifetime for different algorithms, with Enhanced LEACH showing significant improvement compared to other protocols. The results validate the efficiency of Enhanced LEACH in maximizing network longevity and optimizing energy utilization in wireless sensor networks.

The section also looks at how different consensus and network characteristics affect the integrity, efficiency, and mining of blockchain systems. The simulator is compared with Ethereum, a common public blockchain, in terms of generating blocks, stale rate, and throughput. The results show that the proposed simulator outperforms other simulators, achieving higher values for all three metrics. Additionally, validation runs are conducted using data gathered from Ethereum to ensure the accuracy and reliability of the simulator. Overall, the simulation results and validation show that the suggested clustering methods and simulator are useful and efficient in assessing blockchain systems. These findings provide valuable insights for optimizing energy consumption, network longevity, and mining decentralization in wireless sensor networks and blockchain technology.

TABLE III. ALGORITHM SIMULATION PARAMETER

| Parameters | Value |
|---|---|
| Simulation area dimensions | $100 \times 100$ m |
| Sink node coordinates | center and corner |
| Number of nodes | 100 |
| Node placement | Random |
| Initial energy of each node | 0.5 Joule |
| Packet size | 8 Bytes |

### A. Clustering Results and Validation

The performance evaluation of the suggested clustering algorithm was conducted through simulation in a network environment. This environment consisted of a 2-D network with one hundred nodes randomly generated and distributed. MATLAB 2018a was chosen for its reliability in handling clustering algorithms and its ease of simulating various algorithms, enabling a comprehensive comparison of the results. Table III displays the Algorithm parameters used in this instance.

The obtained simulation results demonstrate the usefulness of the suggested clustering model as well as the algorithm's efficiency in reducing overall network energy. Fig. 5 (a) show that the operational nodes per transmission. Fig. 5 (b) illustrates operational nodes per Round. And Fig. 5 (c) shows Energy consumed per transmission.

The provided data in Table VI represents different protocols and their corresponding simulation results in terms of the number of nodes, energy consumption, and the lifespan of the network. The protocols under consideration are Simple LEACH, I-LEACH, Modified LEACH, and proposed Enhanced LEACH.

These protocols are related to wireless sensor networks and aim to optimize energy consumption and network lifetime. Each protocol employs different techniques to manage node energy and prolong the network's operation.
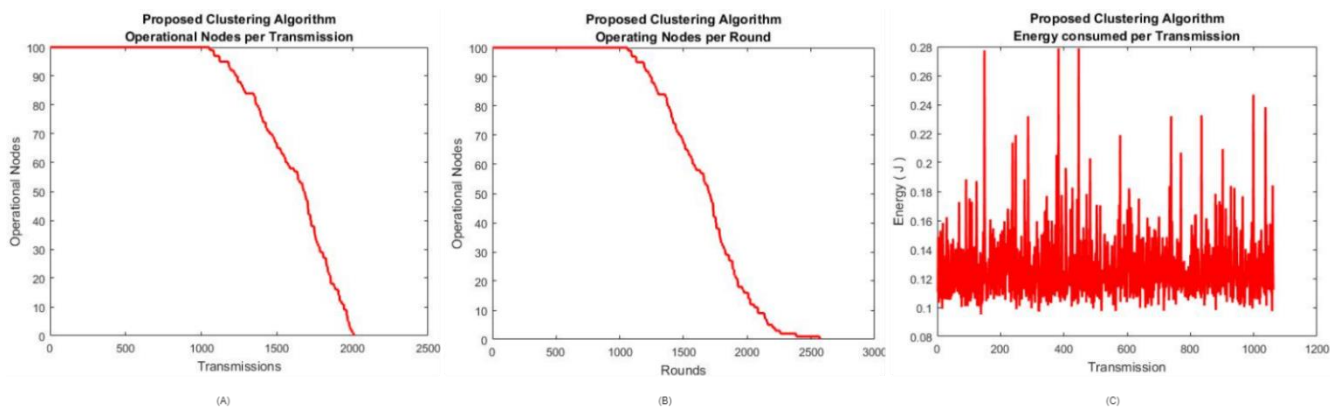
Fig. 5.    Performance of the proposed clustering algorithm. (a): Operational nodes per transmission. (b): Operational nodes per Round. (c): Energy consumed per transmission.

It's important to note that the exact number of nodes and energy values may vary depending on the specific implementation and simulation setup. The "First Node Dies" and "Last Node Dies" metrics indicate the sequence in which nodes exhaust their energy, with a higher number indicating a longer network lifespan.

To determine the best protocol, we need to consider the criteria of maximizing network longevity and minimizing energy consumption. As shown in Fig. 6. Comparison of Protocols in Wireless Sensor Networks, it can be observed that the "Enhanced LEACH" protocol offers the longest network lifespan with the last node dying at 1868 units. This indicates better overall network longevity compared to the other protocols listed. However, the specific energy levels and number of nodes are not provided for a direct comparison.
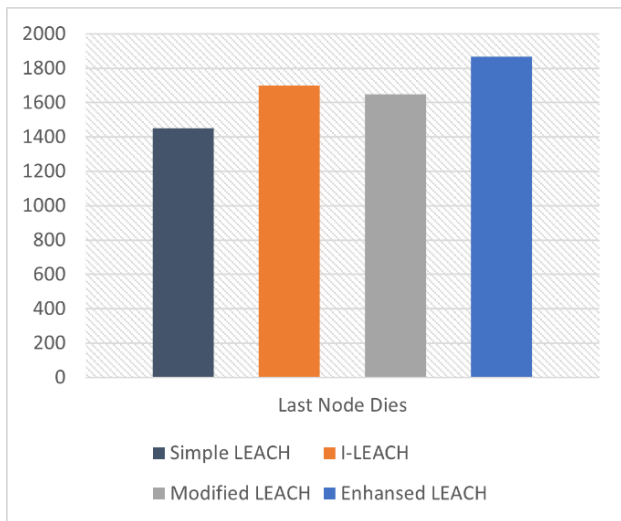


Fig. 6.    Comparison of protocols in wireless sensor networks.

The graph in Fig. 7 depicts the network lifetime in terms of the number of living and dead nodes for various algorithms over a given number of rounds. The x-axis shows the number of rounds, which ranges from 0 to 2000, while the y-axis reflects the number of dead nodes, which ranges from 0 to 100.

In the case of Simple LEACH, Modified LEACH, and I-LEACH algorithms, the number of active nodes decreases rapidly with an increase in rounds. After approximately 1650 rounds, all nodes become inactive, resulting in a network with no active nodes.

However, the proposed Enhanced LEACH algorithm shows a significant improvement in terms of network lifetime. Even after 1650 rounds, some nodes managed to remain active until around 1850 rounds. This indicates that Enhanced LEACH extends the network lifetime compared to the other algorithms.
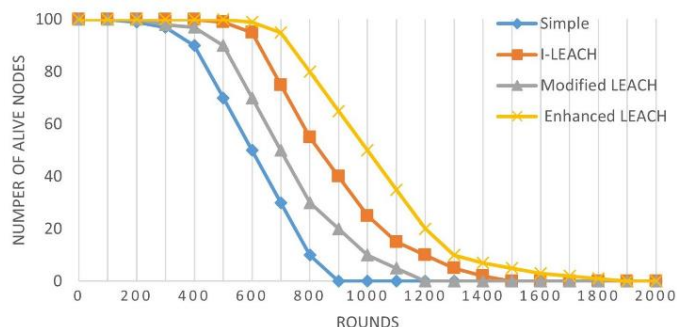


Fig. 7.    Lifetime metrics for different protocols.

TABLE IV.    COMPARISON OF THE PERFORMANCE OF DIFFERENT PROTOCOLS

| Protocols | Nodes | Energy | First Node Dies | Last Node Dies |
|---|---|---|---|---|
| Simple LEACH | 100 | 0.5 | 780 | 1450 |
| I-LEACH | | | 1050 | 1700 |
| Modified LEACH | | | 955 | 1650 |
| Enhanced LEACH | | | 1100 | 1868 |
| Simple LEACH | 100 | 0.5 | 780 | 1450 |
| I-LEACH | | | 1050 | 1700 |

The assignment of different power levels for different forms of communication inside the network is a crucial feature contributing to Enhanced LEACH's enhanced network lifespan. By optimizing power usage and communication strategies, Enhanced LEACH allows for more efficient utilization of energy, resulting in a longer-lasting network.

Overall, the results demonstrate that the Enhanced LEACH algorithm offers improved network lifetime and maximizes the

utilization of sensor nodes' energy resources, making it a promising solution for prolonging the operational time of wireless sensor networks.

### B. Blockchain Simulation Results and Validition

The focus of this section was to examine how the state block rate influences mining decentralization and transaction latency, as well as Ethereum's approach to enhancing block mining decentralization. To compare the results, the simulator's findings were contrasted with those of Ethereum, which is one of the most prominent public blockchains. The comparison included proven invariants, such as block creation frequency and the relationship between a miner's hashing share and their likelihood of winning the Proof of Work competition. Additionally, to validate the simulator, sample public data from Ethereum was also utilized.

We conducted a simulation to assess the impact of different consensus and network settings on the reliability, efficiency, and mining aspects of blockchain systems. The purpose was to demonstrate the capabilities of the simulator, including its performance in terms of run time. The simulation employed validation measures like those used in Ethereum but encompassing a wider range of parameter values.

The Table V presents a comparison of different simulators used in the context of blockchain technology. The simulators are evaluated based on three performance metrics: "B included" (daily number of blocks added to the main blockchain), "Stale Rate" (Uncle rate is the proportion of blocks every day that are not in the main chain), and "Throughput" (number of transactions processed per second).

Based on these findings, the suggested simulator outperforms the other simulators in all three categories. It obtains a higher "B included" number, suggesting that it includes more blocks in the main blockchain every day. The "Stale Rate" is also significantly higher, suggesting that there are somewhat more blocks that are not on the main chain. Furthermore, the "Throughput" figure is larger, suggesting that more transactions are performed per second.

To achieve the outcomes Table VI displays the data collected from Ethereum that was utilized as input to the validation runs. That is, Table VII values were utilized for the appropriate input parameters. The data for Ethereum comes from etherscan.io3. Collected for the purpose of this experiment, fit a frequency distribution with the little data collected.

TABLE V. COMPARISON OF DIFFERENT SIMULATORS

| Simulator | B included | Stale Rate | Throughput |
|---|---|---|---|
| BlockSim [20, 21] | 143 ± 5 | 0.049% ± 0.069% | 2.66 ± 0.09 |
| BlockPerf [22] | 146 ± 4 | 0.025% ± 0.051% | 2.69 ± 0.09 |
| SimChain [23] | 140 ± 6 | 0.032% ± 0.058% | 2.71 ± 0.07 |
| NetSim [24] | 145 ± 3 | 0.042% ± 0.072% | 2.68 ± 0.08 |
| ChainSim [25] | 144 ± 4 | 0.051% ± 0.074% | 2.67 ± 0.09 |
| Proposed Simulator | 150 ± 7 | 0.058% ± 0.081% | 2.75 ± 0.1 |

TABLE VI. DATA GATHERED FROM ETHEREUM

| Parameters | Ethereum |
|---|---|
| B interval | 12.42s |
| B delay | 2.3s |
| B size | 7,997,148 Gas |
| T size | Distribution |

TABLE VII. INPUT PARAMETERS FOR THE SIMULATOR

| Parameters | Value |
|---|---|
| Total Number of Devices | 50 |
| Total Number of Blocks | 100 |
| Blocks in a Chain | 50 |
| TX List Size Limit | 5 |
| Total Number of Transactions | 1000 |
| Average Transaction Latency | 0.005 |
| Transaction Throughput | 50 |
| Simulation Duration (secs) | 20 |

## VI. CONCLUSION

This paper makes significant contributions to the field by tackling the pressing security challenges arising from the exponential growth of IoT nodes. It presents a two-layered blockchain security model, harnessing the inherent decentralization and distribution of blockchain technology to fortify IoT network security. Moreover, the introduction of an enhanced LEACH algorithm, empowered by fuzzy logic, is a noteworthy innovation aimed at optimizing data aggregation and extending the operational lifespan of network nodes. The paper goes even further by introducing a framework that capitalizes on the blockchain's distributed nature to authenticate IoT nodes, structured as a discrete event system model, with a particular focus on network and consensus stages. Through meticulous simulation results, the proposed enhanced LEACH algorithm demonstrates its effectiveness, outperforming previous works and significantly prolonging the network nodes' longevity. In sum, this paper's contributions encompass a two-layered blockchain security model, an enhanced LEACH algorithm, and a blockchain-based authentication framework, all of which exhibit great promise in addressing IoT network security concerns. Future research avenues may delve into exploring the scalability and practical implementation of these proposed models in real-world IoT environments, further solidifying their significance in the domain.

### REFERENCES

[1] Tawalbeh, L.a., et al., IoT Privacy and security: Challenges and solutions. Applied Sciences, 2020. 10(12): p. 4102.

[2] Al-Hadhrami, Y. and F.K. Hussain, DDoS attacks in IoT networks: a comprehensive systematic literature review. World Wide Web, 2021. 24(3): p. 971-1001.

[3] Stoyanova, M., et al., A survey on the internet of things (IoT) forensics: challenges, approaches, and open issues. IEEE Communications Surveys & Tutorials, 2020. 22(2): p. 1191-1221.

[4]  Tao, X., et al., Confidentiality-minded framework for blockchain-based BIM design collaboration. Automation in Construction, 2022. 136: p. 104172.

[5]  Leng, J., et al., Secure blockchain middleware for decentralized iiot towards industry 5.0: A review of architecture, enablers, challenges, and directions. Machines, 2022. 10(10): p. 858.

[6]  Hewa, T., M. Ylianttila, and M. Liyanage, Survey on blockchain based smart contracts: Applications, opportunities and challenges. Journal of network and computer applications, 2021. 177: p. 102857.

[7]  Bhatia, S., et al., Performance analysis of energy efficient improved LEACH protocol in IoT networks. IET Communications, 2022.

[8]  Amjad, S., et al., Blockchain based authentication and cluster head selection using DDR-LEACH in internet of sensor things. Sensors, 2022. 22(5): p. 1972.

[9]  Ramya, R., et al. Energy efficient enhanced LEACH protocol for IoT based applications in wireless sensor networks. in 2022 International Conference on Inventive Computation Technologies (ICICT). 2022. IEEE.

[10] Islam, M.J., et al., Blockchain-SDN-based energy-aware and distributed secure architecture for IoT in smart cities. IEEE Internet of Things Journal, 2021. 9(5): p. 3850-3864.

[11] Yanhui, L., et al., Research on identity authentication system of Internet of Things based on blockchain technology. Journal of King Saud University-Computer and Information Sciences, 2022. 34(10): p. 10365-10377.

[12] Ourad, A.Z., B. Belgacem, and K. Salah. Using blockchain for IOT access control and authentication management. in Internet of Things–ICIOT 2018: Third International Conference, Held as Part of the Services Conference Federation, SCF 2018, Seattle, WA, USA, June 25-30, 2018, Proceedings 3. 2018. Springer.

[13] Yavari, M., et al., An improved blockchain-based authentication protocol for iot network management. Security and Communication Networks, 2020. 2020: p. 1-16.

[14] Gong, L., D.M. Alghazzawi, and L. Cheng, BCoT sentry: A blockchain-based identity authentication framework for IoT devices. Information, 2021. 12(5): p. 203.

[15] Honar Pajooh, H., Blockchain for secured IoT and D2D applications over 5G cellular networks: a thesis by publications presented in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Computer and Electronics Engineering, Massey University, Albany, New Zealand. 2021, Massey University.

[16] Honar Pajooh, H., et al., Multi-layer blockchain-based security architecture for internet of things. Sensors, 2021. 21(3): p. 772.

[17] Kumar, P., et al. A Secure Data Dissemination Scheme for IoT-Based e-Health Systems using AI and Blockchain. in GLOBECOM 2022-2022 IEEE Global Communications Conference. 2022. IEEE.

[18] Kumar, P., et al., Blockchain and Deep Learning for Secure Communication in Digital Twin Empowered Industrial IoT Network. IEEE Transactions on Network Science and Engineering, 2022.

[19] Al Ahmed, M.T., et al., Authentication-Chains: Blockchain-Inspired Lightweight Authentication Protocol for IoT Networks. Electronics, 2023. 12(4): p. 867.

[20] Alharby, M. and A. van Moorsel, Blocksim: An extensible simulation tool for blockchain systems. Frontiers in Blockchain, 2020. 3: p. 28.

[21] Alharby, M., Models and simulation of blockchain systems. 2020, Newcastle University.

[22] Polge, J., et al., BlockPerf: A hybrid blockchain emulator/simulator framework. IEEE Access, 2021. 9: p. 107858-107872.

[23] Ibba, N., T. Wiipongwii, and T.-T.R. Chung, SimChain: Simulator for Supply Chain Decision Making with Blockchain. 2021.

[24] Priyeash, B. and J. Thyagarajan. Performance Evaluation and Comparison Analysis of AODV and RPL Using NetSim in Low Power, Lossy Networks. in International Conference on Futuristic Communication and Network Technologies. 2020. Springer.

[25] Wang, B., et al. Chainsim: A p2p blockchain simulation framework. in Blockchain Technology and Application: Third CCF China Blockchain Conference, CBCC 2020, Jinan, China, December 18-20, 2020, Revised Selected Papers 3. 2021. Springer.

# Fuzzy Failure Modes Effect and Criticality Analysis of the Procurement Process of Artificial Intelligent Systems/Services

Khalid Alshehhi, Ali Cheaitou, Hamad Rashid

Department of Industrial Engineering and Engineering Management
University of Sharjah 27272 Sharjah, United Arab Emirates

*Abstract*—This study focuses on the ranking of risks associated with the procurement of Artificial Intelligent (AI) systems/services for UAE public Sectors. Considering the involvement of human-based reasoning, this study proposes to use Fuzzy Failure Mode Effect and Criticality Analysis (FMECA). The risks were identified from the literature and subsequently, using 40 interviews with practitioners, the final list is developed on the basis of the presence of risks in the AI procurement process. For Fuzzy FMECA, the input data is collected from fifteen experts. The values of Severity (S), and Detection (D) for each risk element are averaged to use as input. If-Then rule-based fuzzy inference system is employed to obtain the Fuzzy Risk Priority Numbers of risk elements. The traditional RPN and Fuzzy RPN numbers are compared and it is found that fuzzy RPN gives a realistic picture of the ranking of risks. Privacy and security risks, Integration Risks, Risk of Malfunction of systems/services, and Ethical risks are found to be high priorities. This study provides valuable insight to policymakers to develop strategies to mitigate these risks for smooth procurement and implementation of AI-related Projects.

*Keywords—Fuzzy Failure Mode Effect and Criticality Analysis (FMECA); procurement; Artificial Intelligent (AI) System; public sector; United Arab Emirates (UAE)*

## I. INTRODUCTION

The United Arab Emirates (UAE) has been at the forefront of embracing technological advancements and digital transformation in the public sector. Artificial Intelligence (AI) systems have emerged as a critical enabler in the UAE public sector, transforming operations, improving decision-making, and delivering efficient and citizen-centric services [1]. The UAE government has led smart government programs aimed at leveraging AI's potential for improved service delivery. These programs are aimed at exploiting Artificial Intelligence (AI) technology in fields such as healthcare, transportation, education, public safety, and e-governance [2]. Artificial intelligence-powered platforms streamline administrative operations, provide personalized services, and enable data-driven decision-making. The UAE public sector hopes to increase operational efficiency, optimize resource allocation, and improve overall service quality by integrating AI technology.

Artificial Intelligence (AI) solutions have received much attention as part of this journey. However, the AI procurement process carries inherent risks that must be identified and handled efficiently [3]. If not adequately handled, these risks can negatively influence the successful adoption and use of AI technology. In addition, AI procurement risks can have financial implications such as operational disruption, Ethical and legal concerns, reputation damage, and missed opportunities [4]. Understanding the effects and putting appropriate risk mitigation measures in place is critical for public sectors looking to reap the advantages of AI while minimizing the negative outcomes. Failure Mode Effect and Criticality Analysis (FMECA) is a tool for identifying risks in complex systems.

FMEA may be used in various processes, including procurement (Skelton, 1997). In the process, it is also utilized to assure the safe functioning of complicated monitoring and control systems. FMEA methodically identifies the impact of risk elements on the system and assesses the importance of each failure mode in terms of system performance. The approach is primarily utilized in a wide range of technologies to investigate and comprehend component/system failure. FMEA is known as failure mode effect criticality analysis (FMECA) when it is used to prioritize failure modes. The failure modes are ranked using the Risk Priority Number (RPN) by FMECA. RPN is frequently computed as the product of failure mode occurrence (O), severity (S), and non-detection (D). According to Certa et al. (2017), O stands for the frequency of occurrence of the failure mode, S for the severity of the harm that particular failure modes with occurrences of O can cause to systems, processes, and the environment, and D stands for the likelihood that the failure modes with occurrences of O and S won't be detected.

Although there are various applications for FMEA, several researchers have highlighted the various shortcomings of the traditional Risk Priority Number (RPN) that is employed in FMEA. The most significant shortcoming is subjectivity and Lack of Consistency. The subjectivity and lack of consistency in the severity, occurrence, and detection ratings given to potential risks by RPN is one of its key issue. The same risk may be evaluated differently by various team members, resulting in variances in the final RPN ratings. This subjectivity can undermine the accuracy of the findings [5]. To overcome this limitation, fuzzy based FMEA was used by various researchers such as [6-9].

The approach for creating a fuzzy RPN (FRPN) is described in this study. It may partially address some of the

constraints mentioned in the literature. The fundamental inputs for producing FRPN are the fuzzified form of frequency, severity, and non-detection of the failure modes. The following stage in fuzzy FMECA is to establish the fuzzy rules. For this stage, the original classes of O, S, and D and the corresponding RPN class are used to establish the rules. The next stage is to use linguistic variables and membership functions to transform the crisp input data into fuzzy values. The assessment of the rule bases created during the study comes next. The last stage to transform the fuzzy output into crisp output is called defuzzification. The AI procurement process in UAE public sectors is subjected to this process. In addition, Comparisons are made between the outcomes of conventional and fuzzy FMECA.

The rest of the paper is as follows: Section II presents the literature review highlighting the rating of risks associated with procurements and tools and techniques for this purpose. Materials and Methods utilized in this study are presented in Section III. Section IV presents the results and discussions. Finally, Section V presents conclusions drawn from this study.

## II. LITERATURE REVIEW

For the procurement process to be effective, risks must be identified and managed. The identification of risks and mitigation processes can be facilitated by a number of efficient tools and methods. The risk register is one such instrument, which entails methodically identifying possible hazards, evaluating their effect and likelihood, and developing suitable mitigation strategies. There are numerous methods/ techniques are employed for risk analysis [10]. Bathrinath, Bhalaji [11] used AHP-TOPSIS method for risk assessment and ranking in a Textile Industry. To analyze the risks in urban stormwater infrastructure systems, Shariat, Roozbahani [12] applied fuzzy spatial multi-criteria decision-making. Data analytics is also applied as a tool for the evaluation and improvement of procurement processes [13]. Delima, Santoso [14] applied a dynamic system development model for the development of purchasing model for agriculture e-commerce. Among all the tools and techniques, Failure Mode and Effect Analysis (FMEA) is a widely used tool for risk analysis.

The FMEA approach, which was developed in the 1960s for the aerospace industry, is a powerful tool for assessing possible risks [15]. In complex systems, this method is very helpful in averting undesirable outcomes [16]. FMEA is widely utilized in a variety of industries, including those in the aerospace, automotive, nuclear, electronics, chemical, mechanical, and medical domains [17-22]. Aldenny, Kristian [23] applied FMEA analysis to determine possible risks with the government's electronic procurement process using the FMEA approach. To improve the purchasing process of public procurement in hospitals, Kumru and Kumru [24] applied the FMEA to indicate the levels of risks associated with potential issues. Nahavandi and Tavakoli [25] applied the FMEA combined with the TOPSIS method to identify the risks associated with procurement in the automotive supply chain. The Modified FMEA is also used for ranking risks associated with military weapons procurement [26]. Handayani [27] also applied the FMEA analysis to evaluate the risks associated

with supplier-buyer transactions in a supply chain procurement. These studies infer that FMEA is an effective tool for analyzing the risks associated with the Procurement process.

There are some limitations of the traditional FMEA process which doesn't capture the subjectivity in a precise way. To overcome this difficulty, a variant of FMEA was developed using a fuzzy set theory known as fuzzy FMEA. Incorporating the criticality analysis in Fuzzy FMEA, the Fuzzy FMECA was developed as an advanced method for ranking the risks. Numerous fields, including engineering [28], manufacturing [29], healthcare [30], and more recently, new technologies like artificial intelligence [31], have found use for fuzzy FMECA. When working with complicated systems where it might be challenging to exactly quantify risk variables, fuzzy FMECA is particularly helpful. Fuzzy FMECA allows decision-makers to consider linguistic variations and subjective aspects by introducing fuzzy logic, making risk analysis more adaptable and understandable.

A crucial step in purchasing cutting-edge technology to improve organizations operations as well as decision-making is the procurement process for Artificial Intelligent (AI) systems or services. Predictive analytics, machine learning, and other disruptive features that AI systems provide have the ability to completely change a number of sectors. It takes strategic decision-making to choose the best AI solutions that fit an organization's objectives, requirements, and capabilities when purchasing AI systems or services. For effective AI integration, suppliers and technology providers must be properly evaluated and chosen [32]. In order to evaluate failure modes, their impacts, and criticality while procuring AI solutions, fuzzy FMECA (Failure Mode Effect and Criticality Analysis) is extremely important. By introducing fuzzy logic, which enables the management of uncertainties and ambiguity frequently found in AI systems, fuzzy FMECA expands classic FMECA approaches. The inherent complexity and changing nature of AI technology make this competence essential in the context of AI procurement [33]. Complex algorithms and learning models are used in AI systems, which might result in erratic and unexpected behavior. Fuzzy FMECA can manage ambiguous inputs and hazy data, providing a more accurate evaluation of likely risk mechanisms [34]. AI systems often produce results with varying degrees of ambiguity. Fuzzy FMECA utilizes linguistic variables to quantify the degree of criticality, providing a more nuanced evaluation of failure effects [35].

## III. MATERIALS AND METHOD

FMECA typically consists of two steps: (i) Use failure mode and effect analysis to distinguish between various failure types and their impacts, (ii) group failure mode criticality analysis according to the likelihood of occurrence and impact [15]. Traditional FMEA calculations involve generating a risk priority number (RPN). Three main factors are needed when doing an FMEA: occurrence (O), which indicates the likelihood of accident occurrences. The term "severity" (S) refers to the seriousness of the consequences of failure modes not being detected. Non-detection (D) eliminates the possibility of detecting failures before they occur. The sum of the three

aforementioned operations yields a risk level known as the risk priority number (RPN).

The shortcomings of the traditional Risk Priority Number (RPN) employed in FMEA have been noted by several academics. The relative relevance of O, S, and D is not often considered in most FMEA analyses, according to Wang, Chin [36]. According to [37], different O, S, and D combinations may result in exactly the same RPN number, but their hidden risk implications may be quite different.

An intelligent framework that summarizes established multi-valued logic for problem-solving under vulnerability is referred to as fuzzy logic. Control designers may easily implement control methodologies used by human administrators thanks to fuzzy logic [38]. Its structure is based on the fact that some problems might be solved based on related knowledge or expert learning while others did not require the proper or accurate esteem. It is based on a likelihood hypothesis for the conversion of crisp to fuzzy input, which will be handled by referring to the state of the fuzzy rule base created by experts. Fuzzy rule base preparation, which converts fuzzy output to crisp output, might solve the problem. Fuzzy logic was a mechanism for making decisions when information was vulnerable and taking flexibility into account.

It is feasible to obtain a complete description of potential risk and its impact by using fuzzy logic in failure modes, effects, and criticality analysis (FMECA). This strategy might effectively address the problems and clearly identify any risks and implications. Furthermore, it could also build trust at the same time. It enables an assessor to directly assess the risks associated with failure by using language concepts in criticality evaluation. Ambiguity, subjective information, or data including quantitative information may be used in the evaluation and organization, although not always unambiguously. The combination of severity (S), occurrence (O), and non-detection (D) parameters had a more flexible structural design. The use of fuzzy logic in FMECA for ranking the risks associated with the procurement of AI systems/services is the main topic of this paper.

*A. The Proposed Method*

The proposed method is based on the work done by Makowski and Mannan [39]. Risk is normally evaluated using two components, severity, and occurrence, during the risk assessment process. Traditional risk predicts frequency and severity as discrete values/categories. Due to a number of uncertainties, frequency and severity values are non-crisp in nature [39]. When there are uncertainties in the parameters used for risk computation, fuzzy logic can be employed to estimate the risk. In the classification of these characteristics, fuzzy logic does not identify precise limits. The fuzzy risk matrix is created by combining a fuzzy frequency and a fuzzy severity.

The RPN in the FMECA research makes use of three parameters: O, S, and D. O, S, and D crisp input data are generally quantified on a ten-point scale (see Tables I to III). Using linguistic expressions and membership functions, they are turned into fuzzy values. Similarly, the output's membership function (RPN) is constructed. In this study, 1000

rules were designed to govern the output value. As an example (rule No. 996), if the occurrence is definite (10), the severity is substantial (6), and the detection is not possible, RPN is calculated conventionally by multiplying O, S, and D (10*6*6) = 360. The standard RPN, which corresponds to class 9, has been improved by integrating the linguistic phrase "high" matching to this class. A Mamdani fuzzy inference technique is used to convert qualitative rules into quantitative results. The fuzzy set for each rule is aggregated once the rules have been assessed. The centre of area approach is utilised for defuzzification in this work.

TABLE I.  OCCURRENCE SCALES USED IN FMECA OCCURRENCE 'O'

| Rank | Probability of failures | Human error occurrence Probability | Linguistic Variable |
|---|---|---|---|
| 1 | < 1:20000 | < every 5 years | Unlikely |
| 2 | 1:20000 | In 3–5 years | Very remote |
| 3 | 1:10000 | In 1–3 years | remote |
| 4 | 1:2000 | Per year | Very low |
| 5 | 1:1000 | In every 6 months | Low |
| 6 | 1:200 | In every 3 months | Moderate |
| 7 | 1:100 | Per months | Moderately high |
| 8 | 1:20 | Per Week | High |
| 9 | 1:10 | Every few days | Very high |
| 10 | 1:2 | Per Day | Almost certain |

(Courtesy:M. Giardina, M. Morale/Journal of Loss Prevention in the Process Industries 35(2015),35–45).

TABLE II.  SEVERITY SCALES USED IN FMECA SEVERITY 'S'

| The severity of Each risk | Effect | Rank |
|---|---|---|
| No reason to expect risk to have any effect on safety, health, environment, or mission | None | 1 |
| Very minor effect on product or system performance to have any effect on safety or health. The system does not require repair / restart. | Very Minor | 2 |
| Minor effect on product or system performance to have any effect on safety or health. The system can require repair/ restart. | Minor | 3 |
| Very low effect on system performance. A failure is not serious enough to cause injury, property damage, or system damage, but can result in unscheduled maintenance or repair | Low | 4 |
| Moderate effect on system performance. The system requires repair. A failure may cause moderate injury, moderate property damage, or moderate system damage which will result in delay or loss of system availability or mission degradation. 100% of the mission may need to be reworked or process delayed. | Moderate | 5 |
| System performance is degraded. Some safety functions may not operate. A failure causes injury, property damage, or system damage. Some portion of mission is lost. High delaying restoring function. | Significant | 6 |
| System performance is severely affected but functions (reduced level of safety performance). The system may not operate. Risk does not involve noncompliance with government regulations or standards. | Major | 7 |
| System is inoperable with loss of primary function. Risk can involve hazardous outcomes and/or noncompliance with government regulations or standards. | Extreme | 8 |

| Risk involves hazardous outcomes and/or noncompliance with government regulations or standards. Potential safety, health or environmental issue. Risk will occur with warning. | Very Extreme | 9 |
|---|---|---|
| Risk is hazardous and occurs without warning. It affects safe operation. A Risk is serious enough to cause injury, property damage, or system damage. Risk will occur without warning. | Serious | 10 |

TABLE III.    DETECTION SCALES USED IN FMECA DETECTION 'D'

| Likelihood of detection of risk | Degree of Importance | Probability of failure of detection | rating |
|---|---|---|---|
| Current control(s) almost certainly will detect a potential risk. | Almost certain | 0-10 | 1 |
| Very likelihood system will detect risk. | Very High | 10-20 | 2 |
| High chance the system will almost certainly detect a potential risk. | High | 20-30 | 3 |
| Moderately high likelihood system will detect risk. | Moderately High | 30-40 | 4 |
| Moderate chance that the system will detect a risk. | Moderate | 40-50 | 5 |
| Low likelihood system will detect risk. | Low | 50-60 | 6 |
| Very low likelihood system will detect risk. | Very Low | 60-70 | 7 |
| Remote chance that the system will detect a risk. | Remote | 70-80 | 8 |
| Risk most likely remains undetected. | Very Remote | 80-90 | 9 |
| Risk is not detectable. | Almost Impossible | 90-100 | 10 |

TABLE IV.    RISK CLASSIFICATION ON BASICS OF FUZZY RPN

| Trapezium Membership function | Linguistic Variable | Rank |
|---|---|---|
| [0,0,100,200] | None | 1 |
| [100,200,200,300] | Very low | 2 |
| [200,300,300,400] | Low | 3 |
| [300,400,400,500] | High low | 4 |
| [400,500,500,600] | Low medium | 5 |
| [500,600,600,700] | Medium | 6 |
| [600,700,700,800] | High medium | 7 |
| [700,800,800,900] | Low high | 8 |
| [800,900,900,1000] | High | 9 |
| [900,900,1000,1000] | Very high | 10 |

The main purpose of the AI procurement process in the public sector is to fulfil the requirements of public administration, such as government modernization and digitalization (Wegener & Müller, 2018). It can also be regarded as a means to promote good governance (Mehr, 2017; Solihati & Indriyani, 2021). The AI procurement process

involves managing materials, purchasing transactions, and activities to ensure the quality of purchased AI products based on the requirements set for them (Karlsson, 2020). It involves all functions, from identifying needs to the selection of sources and awarding and administration of contracts as shown in Fig. 1.
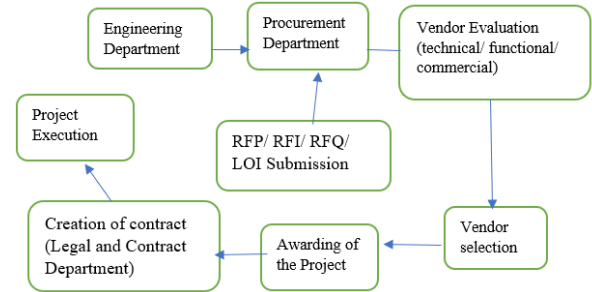


Fig. 1.   AI procurement process common to the UAE Public Sectors.

AI procurement risks refer to those risks which are associated with the purchase of AI technologies/systems. The increased visibility of associated risks in AI projects led to a more strident clamour for ethical, legal, and secure adoption. Based on the literature and subsequent interviews with practitioners from UAE public sectors, the participants identified the following risks in the procurement of AI projects in their respective organizations: privacy and security risks, integration risk, skills risk, risk of time frame, the risk of financial economic loads, and risk regarding vendors. They also identified other risks such as risk of miscommunication and the risk of system malfunction. The list of risks was also validated by a focus group discussion. The risks and their definitions are represented in Table V.

TABLE V.    BRIEF DESCRIPTION OF RISKS ASSOCIATED WITH AI PROCUREMENT PROCESS

| Risk | Definition |
|---|---|
| Privacy and security risk | Privacy risk refers to the likelihood of experiencing problems arising from data processing and the impact that it may bring. Security risk deals with the possibility of losses resulting from information security concerns. |
| Ethical risk | It is associated with the possibility of reputational or moral harm to individuals or organizations. In AI procurement, this risk involves moral dilemmas due to the process of AI-driven dehumanization and displacement of human control |
| Integration Risk | In AI procurement, it refers to the probability of failure of the integration of systems, technologies, or information due to system incompatibility. |
| Skill-related Risk | It deals with the likelihood of lack of or inadequate skills that the workforce may encounter by introducing new technology to the organization. |
| Legal risk | It refers to the potential failure of an organization to comply with regulations or terms of the contract. In AI procurement, AL algorithms or data misuse can lead to legal liability risks. |
| Risk of Environmental Sustainability influencing Hazards | It refers to the probability of hazards posed against maintaining an ecological balance in the natural environment and against conserving natural resources for the utilization of current and future generations. |
| Financial Load risk | It refers to the probability of losing money or danger than can lead to the loss of capital. In AI procurement, financial load risk may be due to exceeding allocated budget. |

| Time frame-related risk | It deals with the possibility of time impacting the project, such as delay. In AI procurement, this risk can lead to cost overruns. |
|---|---|
| Vendor related risk | It refers to risks associated with vendors, such as delays caused by vendors, overpricing of technology provided, security breaches, and unforeseen vendor in capabilities, amongst others, which can cause reputational damage to the organization. |
| Risk of Miscommunication | It refers to the likelihood of the personnel or workforce to fail to communicate adequately (including top-bottom and bottom-up channels of information flow). In AI procurement, this can lead to bias in decision-making. |
| Risk of System Malfunction | It deals with the probability of system failure, error, or malfunctioning. In AI procurement, this may arise from not being able to regularly update the system's network. |

Fuzzy FMECA was performed for AI Procurement process (see Fig. 1). To identify the risk elements, Literature review, Interviews with experts and Focus group discussion were employed. The validated list of risks is presented in Table V. In the proposed study fuzzy logic is used to address the issues in prioritization of these risks. In expert elicitation, the experts, from UAE public sector with extensive understanding of the AI procurement process, used fuzzy language phrases to define the risk variables O, S, and D. The O, S, D values for each risk are collected from the experts using an online survey. In total, 22 responses were recorded. The seven responses were discarded as data were missing or non-serious inputs are seen. Finally, we have taken the average value of O, S, and D for each risk elements and traditional RPN was calculated as shown in Table VI. RPN is a class based on the classes of O, S, and D assigned by the expert, rather than a product of multiplied values of O, S, and D.

TABLE VI. RPN AND PRIORITISATION OF RISKS

| Sl. No. | Risks | Occurrence ranking | Severity Ranking | No-Detection Ranking | RPN | Priority |
|---|---|---|---|---|---|---|
| 1 | Privacy and Security Risk | 8 | 8.1 | 5.3 | 343 | 1 |
| 2 | Ethical Risk | 5.7 | 6.9 | 5.8 | 228 | 3 |
| 3 | Integration Risk | 7 | 7.1 | 4.8 | 239 | 2 |
| 4 | Skill Related Risk | 6.1 | 5.9 | 4.8 | 173 | 7 |
| 5 | Legal Risks | 5.2 | 6.3 | 6.2 | 203 | 5 |
| 6 | Environmental Risk | 4 | 6.3 | 5.7 | 144 | 11 |
| 7 | Financial Risk | 6.2 | 6.2 | 4.3 | 165 | 9 |
| 8 | Time Frame Related Risk | 6 | 5.6 | 4.9 | 165 | 9 |
| 9 | Vendor Related Risk | 6.3 | 5.8 | 4.6 | 168 | 8 |
| 10 | Miscommunication Risks | 5.7 | 6.7 | 5.3 | 202 | 6 |
| 11 | System Malfunction Risk | 6.2 | 6.9 | 5 | 214 | 4 |

The different scales used to measure the two components O and S are shown in Tables I and II. The scale used to measure the parameter D is shown in Table III. These measures assess the likelihood of occurrence, severity, and likelihood of non-detection (see Table IV). The risks data came from a survey

based on experts' opinion for AI procurement Process risk analysis. 11 risk elements were identified and prioritized based on the appropriate RPN score (see Table VI).

Fig. 2 depicts an overview of the fuzzy logic method. The study consists of three primary steps: (i) Fuzzification employing linguistic variables to turn the three risk factors S, O, and D into fuzzy membership functions. (ii) Rule assessment based on expert knowledge of the relationships between various risks and the effect, as represented by fuzzy if-then rules. (iii) A de-fuzzification technique generates a crisp ranking from the fuzzy RPN to provide the failure mode prioritization level.
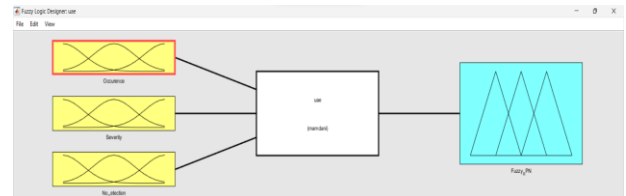


Fig. 2. Schematic of fuzzy logic process for FMECA Using Matlab FIS editor.

The complete fuzzification procedure was carried out in MATLAB using the fuzzy toolbox, with the triangular membership function representing the inputs O, S, and D as shown in Fig. 3(a), 3(b), and 3(c). The triangular membership function was also employed to depict the FRPN output membership functions (see Fig. 4).



(a)



(b)



(c)
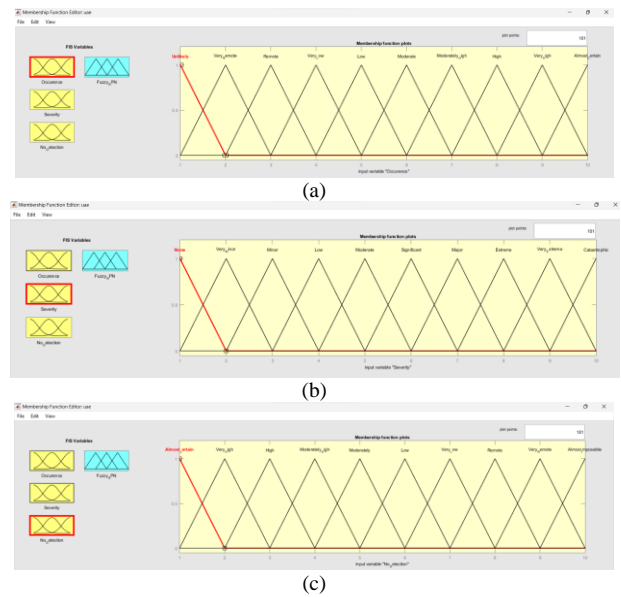
Fig. 3. (a): Membership functions for input variable 'Occurrence', (b): Membership functions for input variable 'Severity', (c): Membership functions for input variable 'Detection'.
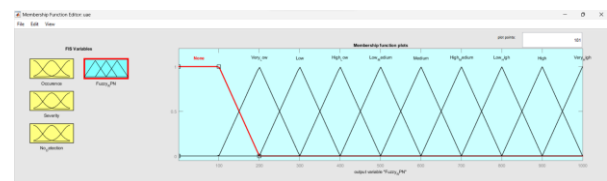


Fig. 4. Membership functions for Output variable 'Fuzzy RPN'.
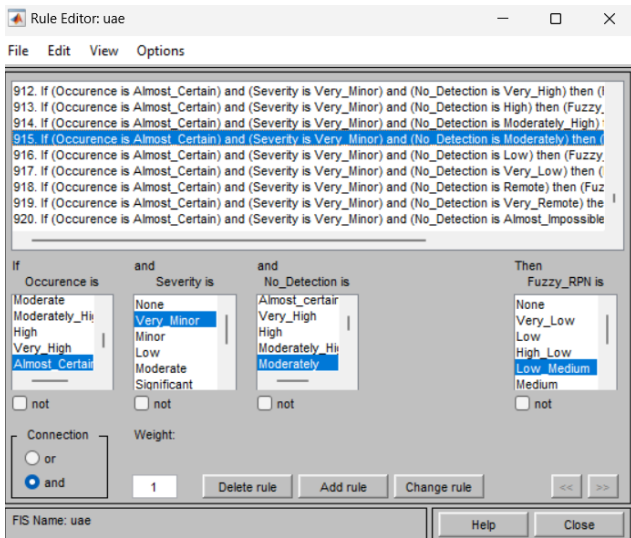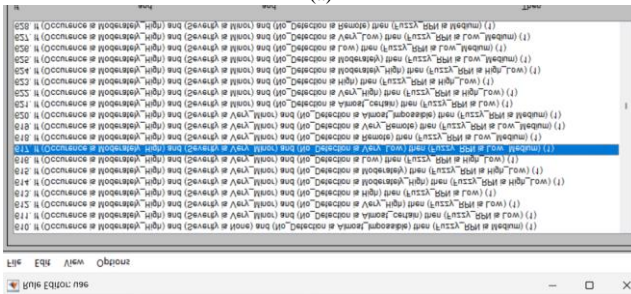
Fig. 5. (a): Rule base developed for relating O, S &D to FRPN using expert elicitation, (b): Rule base developed for relating O, S &D to FRPN using expert elicitation.
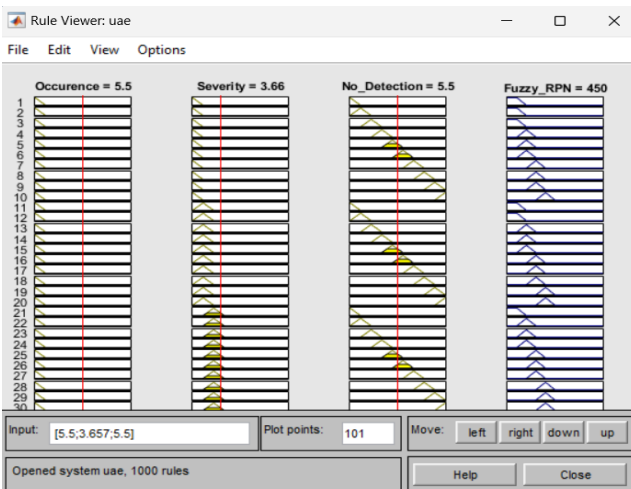


Fig. 6. Defuzzification at the rule plot in Matlab.

The input values of O, S, and D were provided by experts. As 15 experts' opinions were considered, an average value of O, S and D were taken into consideration. For the analysis, 1000 if then rules were developed as shown in Fig. 5(a) and (b). These criteria are intended to cover all conceivable O, S, and D combinations. The Mamdani min/max inference mechanism is utilised (input method: min; aggregate method:

max), and the results are defuzzied using the centre of gravity approach (see Fig. 6).

## IV. RESULTS AND DISCUSSION

A basic condition for fuzzy inference applications is that the fuzzy system's output be monotonic with regard to its inputs [40]. The suggested model's rule base is nondecreasing as can be seen from the output surface plots as shown in Fig. 7(a), (b), (c).
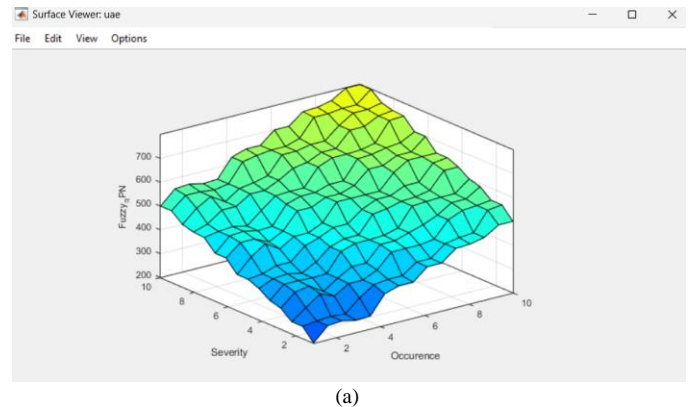


(a)
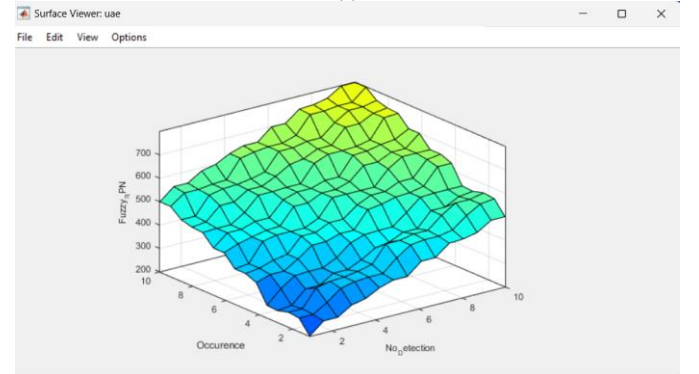


(b)
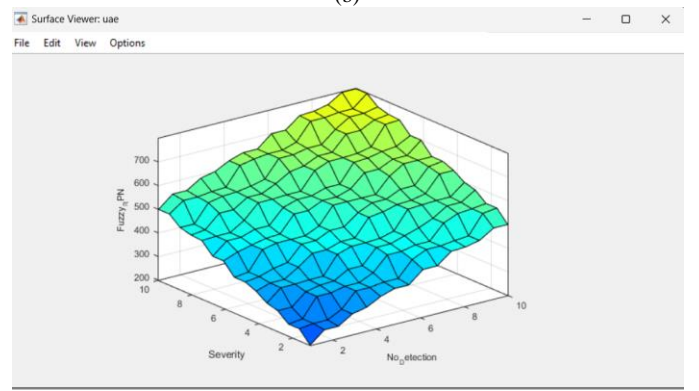


(c)

Fig. 7. (a): Surface plot of Occurrence and severity vs. FRPN in Matlab Surface viewer., (b): Surface plot of Occurrence and No-Detection vs. FRPN in Matlab Surface viewer. (c): Surface plot of Severity and No-Detection vs. FRPN in MATLAB Surface viewer

The values of the inputs (O, S, and D) from the data collecting process are supplied to the FIS system during implementation and result extracted to produce the Fuzzy RPN. The Fuzzy RPN values associated with each risk is shown in Table VII along with priority. It can be seen that the

distribution of output value of Fuzzy RPN is more uniform compared to traditional RPN. It can be also seen that Fuzzy RPN numbers obtained are more realistic to interpret. For example, using conventional process, RPN is calculated conventionally by multiplying O, S, and D (10*6*6) = 360. The standard RPN, which corresponds to class 7, has been improved by integrating the linguistic phrase "high medium" matching to this class.   In order to compare and validate, the ranking of risk elements based on Fuzzy RPN, As demonstrated in Table VII, a focus group discussion was conducted. The experts from public sector of UAE government were invited and provided with the ranking obtained by this study. Majority of experts expressed their agreement with the ranking obtained by this method.

TABLE VII.    FUZZY RPN AND PRIORITISATION OF RISKS

| Sl. No. | Risks | Occurrence ranking | Severity Ranking | No-Detection Ranking | Fuzzy RPN | Priority |
|---|---|---|---|---|---|---|
| 1 | Privacy and Security Risk | 8 | 8.1 | 5.3 | 700 | 1 |
| 2 | Ethical Risk | 5.7 | 6.9 | 5.8 | 578 | 4 |
| 3 | Integration Risk | 7 | 7.1 | 4.8 | 600 | 2 |
| 4 | Skill Related Risk | 6.1 | 5.9 | 4.8 | 511 | 9 |
| 5 | Legal Risks | 5.2 | 6.3 | 6.2 | 531 | 7 |
| 6 | Environmental Risk | 4 | 6.3 | 5.7 | 500 | 10 |
| 7 | Financial Risk | 6.2 | 6.2 | 4.3 | 522 | 8 |
| 8 | Time Frame Related Risk | 6 | 5.6 | 4.9 | 500 | 10 |
| 9 | Vendor Related Risk | 6.3 | 5.8 | 4.6 | 532 | 6 |
| 10 | Miscommunication Risks | 5.7 | 6.7 | 5.3 | 569 | 5 |
| 11 | System Malfunction Risk | 6.2 | 6.9 | 5 | 589 | 3 |

The results obtained suggest that Privacy and Security risk is predominant in the case of AI Procurement Process. Various studies also suggested that the privacy and security risk is very important compared to others [41, 42]. The privacy and security risks involved with data privacy concerns, data security vulnerabilities, algorithm biasness, lack of transparencies, adversarial attacks on the system, dependency of third-party vendors and so on. Considering the stakes involved, this risk is considered as most important and having highest impact among all risks.

The next risk of major concern is the integration risk. The integration risk may be faced due to various issues such as data compatibility, system compatibility, customization requirements, skill gaps, user adoption, performance and scalability and vendor reliability. The integration risk is also found to be very important [43].  Considering the importance of integration for example even a city-level law enforcement agency, for example, may not be aware of all the systems utilised across its many departments, how data is linked, and how the outputs shape their practises and policies. Sanchez-Graells, A. [3] highlighted that integration risk makes it difficult for the public and civil society to engage with the appropriate partners, gather information, and hold anybody accountable.

The risk of system malfunction is also found to be a risk of high impact especially in areas where human life at stake such as healthcare sector [44]. The AI system malfunction can be happening due to various factors such as system complexity and maturity, data quality and biasness, model transparency, improper testing and validation, lack in robustness of model, integration issues with existing system, security measures which prevent unauthorised use. During the procurement phase, due care to be taken so that system malfunction cannot happen.

Another risk that is categorized of moderately high impact is ethical risk which associated with raise ethical concerns and may result in harm to individuals, communities, or society as a whole. Kuziemski, M. et al. [45] also support that as AI technologies grow more prevalent, organisations must address the ethical implications during the purchase process.

Risk of miscommunication is also found to be of moderately high impact. In AI procurement, miscommunication risks relate to the possibility of misunderstandings, misinterpretations, or imprecise communication between the parties engaged in the procurement process. As per Grewal and Sridhar [46], these risks might develop at any point during the procurement process, from early planning and needs collection to contract negotiations and implementation. Miscommunication can result in a variety of obstacles and issues, including unclear requirements, misaligned expectations, inaccurate scope and cost estimation, lack of understanding of technical specifications, data access and ownership, and vendor capabilities.

Other risk elements that are vendor related risks are found to be of moderate impact. In the AI procurement process, vendor-related risks refer to potential obstacles or concerns that result from the selection and engagement of an AI vendor or service provider. Choosing the correct vendor is critical since it has a direct influence on the success of the AI project and the organization's ability to meet its goals. Chopra A. [47] has identified several vendor-related concerns in artificial intelligence procurement such as vendor reputation and reliability, Vendor's financial stability, lack of expertise and experience, Vendor lock-in, intellectual property issues, cultural fit, etc..

The legal risks involved in procurement of AI system or services are found to be moderate impact. This risk consists of issues arising due to intellectual property rights, data ownership and usage, data compliance, regulatory requirements, etc. Other risk elements are found to be of low to moderately low impacts are risk associated with time frame, finances, skill related and environmental risks.  It should be noted that from the perspective of UAE public sectors, finance is not considered to be a major concern as well as skills. Further, timeframe and environmental related risks are also found to be of low impact on the AI procurement Process.

## V. CONCLUSION

The proposed Fuzzy FMECA method was applied to rank the risks involved in the procurement of AI Services/ Systems in UAE Public Sectors. The study was carried out by employing fuzzy linguistic variables for occurrence, severity, and non-detection, and then combining these variables using an if-then rule base to achieve Fuzzy RPN or FRPN. The outcomes of traditional FMECA and fuzzy FMECA approaches are compared. Fuzzy FMECA has been proven to be an excellent approach for prioritizing the risks associated with AI procurement Process. The Privacy and security risk are found to be most important, then, Integration risk and system malfunction risks. Other Moderately impact risks are ethical risk, miscommunication risk, vendor related risk and legal risks. The risk associated with finances, skills, environment and time frame were found be of moderate or low impact. The ranking of these risks is validated by a focus group study. This method can be extended to rank the risks involved in other complex systems or prioritizing the different alternatives for decision making.

## REFERENCES

[1] Halaweh, M., Artificial intelligence government (Gov. 3.0): the UAE leading model. Journal of Artificial Intelligence Research, 2018. 62: p. 269-272.

[2] AE, U., UAE national strategy for artificial intelligence 2031. 2018.

[3] Hickok, M., Public procurement of artificial intelligence systems: new risks and future proofing. AI & society, 2022: p. 1-15.

[4] Sanchez-Graells, A., Governing the Assessment and Taking of Risks in Digital Procurement Governance. To be included in A Sanchez-Graells, Digital Technologies and Public Procurement. Gatekeeping and experimentation in digital public governance (OUP, forthcoming), 2022.

[5] Mikulak, R.J., R. McDermott, and M. Beauregard, The basics of FMEA. 2017: CRC press.

[6] Chin, K.-S., A. Chan, and J.-B. Yang, Development of a fuzzy FMEA based product design system. The International Journal of Advanced Manufacturing Technology, 2008. 36: p. 633-649.

[7] Chanamool, N. and T. Naenna, Fuzzy FMEA application to improve decision-making process in an emergency department. Applied Soft Computing, 2016. 43: p. 441-453.

[8] Balaraju, J., M.G. Raj, and C.S. Murthy, Fuzzy-FMEA risk evaluation approach for LHD machine–A case study. Journal of Sustainable Mining, 2019. 18(4): p. 257-268.

[9] Baykasoğlu, A. and İ. Gölcük, Comprehensive fuzzy FMEA model: a case study of ERP implementation risks. Operational Research, 2020. 20: p. 795-826.

[10] Tixier, J., et al., Review of 62 risk analysis methodologies of industrial plants. Journal of Loss Prevention in the process industries, 2002. 15(4): p. 291-303.

[11] Bathrinath, S., R. Bhalaji, and S. Saravanasankar, Risk analysis in textile industries using AHP-TOPSIS. Materials Today: Proceedings, 2021. 45: p. 1257-1263.

[12] Shariat, R., A. Roozbahani, and A. Ebrahimian, Risk analysis of urban stormwater infrastructure systems using fuzzy spatial multi-criteria decision making. Science of the Total Environment, 2019. 647: p. 1468-1477.

[13] TAN, M.H. and W.L. LEE, Evaluation and improvement of procurement process with data analytics. International Journal of Advanced Computer Science and Applications, 2015. 6(8): p. 70.

[14] Delima, R., et al., Development of purchasing module for agriculture e-Commerce using Dynamic System Development Model. International Journal of Advanced Computer Science and Applications, 2018. 9(10).

[15] Bowles, J.B. and C.E. Peláez, Fuzzy logic prioritization of failures in a system failure mode, effects and criticality analysis. Reliability engineering & system safety, 1995. 50(2): p. 203-213.

[16] Sankar, N.R. and B.S. Prabhu, Modified approach for prioritization of failures in a system failure mode and effects analysis. International Journal of Quality & Reliability Management, 2001. 18(3): p. 324-336.

[17] Putcha, C.S., et al., A case study on FMEA applications to system reliability studies. International Journal of Reliability, Quality and Safety Engineering, 2008. 15(02): p. 159-166.

[18] Vinodh, S. and D. Santhosh, Application of FMEA to an automotive leaf spring manufacturing organization. The TQM Journal, 2012. 24(3): p. 260-274.

[19] Mirghafoori, S.H., H. Sayyadi Tooranloo, and S. Saghafi, Diagnosing and routing electronic service quality improvement of academic libraries with the FMEA approach in an intuitionistic fuzzy environment. The Electronic Library, 2020. 38(3): p. 597-631.

[20] Wu, Z., et al., Nuclear product design knowledge system based on FMEA method in new product development. Arabian Journal for Science and Engineering, 2014. 39: p. 2191-2203.

[21] Ho, C.-C. and M.-S. Chen, Risk assessment and quality improvement of liquid waste management in Taiwan University chemical laboratories. Waste management, 2018. 71: p. 578-588.

[22] Chiozza, M.L. and C. Ponzetti, FMEA: a model for reducing medical errors. Clinica chimica acta, 2009. 404(1): p. 75-78.

[23] Aldenny, M., et al. The Implementation of Failure Mode and Effects Analysis (FMEA) of the Information System Security on the Government Electronic Procurement Service (LPSE) System. in Pervasive Computing and Social Networking: Proceedings of ICPCSN 2021. 2022. Springer.

[24] Kumru, M. and P.Y. Kumru, Fuzzy FMEA application to improve purchasing process in a public hospital. Applied soft computing, 2013. 13(1): p. 721-733.

[25] Nahavandi, N. and P. Tavakoli, RISK MANAGEMENT OF PROCUREMENT PROCESSES IN AUTOMOTIVE SUPPLY CHAIN; BAHMAN MOTOR COMPANY. International Journal of Industrial Engineering, 2022. 29(1).

[26] Rai, R.N., Select study of procurement process and availability improvement in military aviation. 2013, IIT Delhi.

[27] Handayani, D.I., Risk Management Of Supplier-Buyer In Procurement Of Raw Materials For Improving Supply Chain Performance. Jurnal Manajemen, 2018. 22(3): p. 293-309.

[28] Ahmed, S. and X.-C. Gu, Accident-based FMECA study of Marine boiler for risk prioritization using fuzzy expert system. Results in Engineering, 2020. 6: p. 100123.

[29] Erozan, İ., A fuzzy decision support system for managing maintenance activities of critical components in manufacturing systems. Journal of Manufacturing Systems, 2019. 52: p. 110-120.

[30] Iadanza, E., et al., Fuzzy FMECA Process Analysis for Managing the Risks in the Lifecycle of a CBCT Scanner. IEEE Access, 2021. 9: p. 135723-135741.

[31] Zúñiga, A.A., J.F. Fernandes, and P.J. Branco, Fuzzy-Based Failure Modes, Effects, and Criticality Analysis Applied to Cyber-Power Grids. Energies, 2023. 16(8): p. 3346.

[32] Renjith, V., P.H. Kumar, and D. Madhavan, Fuzzy FMECA (failure mode effect and criticality analysis) of LNG storage facility. Journal of loss prevention in the process industries, 2018. 56: p. 537-547.

[33] Kinkel, S., M. Baumgartner, and E. Cherubini, Prerequisites for the adoption of AI technologies in manufacturing–Evidence from a worldwide sample of manufacturing companies. Technovation, 2022. 110: p. 102375.

[34] Wan, N., et al., Risk assessment in intelligent manufacturing process: a case study of an optical cable automatic arranging robot. Ieee Access, 2019. 7: p. 105892-105901.

[35] Sarwar, M., G. Ali, and N.R. Chaudhry, Decision-making model for failure modes and effect analysis based on rough fuzzy integrated clouds. Applied Soft Computing, 2023. 136: p. 110148.

[36] Wang, Y.-M., et al., Risk evaluation in failure mode and effects analysis using fuzzy weighted geometric mean. Expert systems with applications, 2009. 36(2): p. 1195-1207.

[37] Liu, H.-C., L. Liu, and N. Liu, Risk evaluation approaches in failure mode and effects analysis: A literature review. Expert systems with applications, 2013. 40(2): p. 828-838.

[38] Yen, J., Fuzzy logic: intelligence, control, and information. 1999: Pearson Education India.

[39] Makowski, A. and S. Mannan, Fuzzy logic for piping risk assessment. Journal of Loss Prevention in the Process Industries, 2009. 22(6): p. 921-927.

[40] Kouikoglou, V.S. and Y.A. Phillis, On the monotonicity of hierarchical sum–product fuzzy systems. Fuzzy sets and systems, 2009. 160(24): p. 3530-3538.

[41] Dilmaghani, S., et al. Privacy and security of big data in AI systems: A research and standards perspective. in 2019 IEEE International Conference on Big Data (Big Data). 2019. IEEE.

[42] Gopalan, S.S., A. Raza, and W. Almobaideen. IoT security in healthcare using AI: A survey. in 2020 International Conference on Communications, Signal Processing, and their Applications (ICCSPA). 2021. IEEE.

[43] Spreitzenbarth, J.M., H. Stuckenschmidt, and C. Bode, The state of artificial intelligence: Procurement versus sales and marketing, in Supply Management Research: Aktuelle Forschungsergebnisse 2022. 2022, Springer. p. 173-193.

[44] Ayling, J. and A. Chapman, Putting AI ethics to work: are the tools fit for purpose? AI and Ethics, 2022. 2(3): p. 405-429.

[45] Kuziemski, M. and G. Misuraca, AI governance in the public sector: Three tales from the frontiers of automated decision-making in democratic settings. Telecommunications policy, 2020. 44(6): p. 101976.

[46] Grewal, R. and S. Sridhar, Commentary: Toward formalizing social influence structures in business-to-business customer journeys. Journal of Marketing, 2021. 85(1): p. 98-102.

[47] Chopra, A. AI in supply & procurement. in 2019 Amity International Conference on Artificial Intelligence (AICAI). 2019. IEEE.

# An Automatic Nuclei Segmentation on Microscopic Images using Deep Residual U-Net

Ramya Shree H P, Minavathi, Dinesh M S

Computer Science & Engineering
PES College of Engineering
Mandya, Karnataka, India

*Abstract*—**Nuclei Segmentation is the preliminary step towards the task of medical image analysis. Nowadays, there exists several deep learning-based techniques based on Convolutional Neural Networks (CNNs) for the task of nuclei segmentation. In this study, we present a neural network for semantic segmentation. This network harnesses the strengths in both residual learning and U-Net methodologies, thereby amplifying cell segmentation performance. This hybrid approach also facilitates the creation of network with diminished parameter requirement. The network incorporates residual units contributes to a smoother training process and mitigate the issue of vanishing gradients. Our model is tested on a microscopy image dataset which is publicly available from the 2018 Data Science Bowl grand challenge and assessed against U-Net and several other state-of-the-art deep learning approaches designed for nuclei segmentation. Our proposed approach showcases a notable improvement in average Intersection over Union (IoU) gain compared to prevailing state-of-the-art techniques, by exhibiting a significant margin of 1.1% and 5.8% higher gains over the original U-Net. Our model also excels across various key indicators, including accuracy, precision, recall and dice-coefficient. The outcomes underscore the potential of our proposed approach as a promising nuclei segmentation method for microscopy image analysis.**

*Keywords—Nuclei segmentation; convolutional neural networks; neural networks; U-Net; deep learning; semantic segmentation; 2018 data science bowl*

## I. INTRODUCTION

Microscopic image analysis continues to serve as a benchmark in the diagnosis and prognostication of various types of cancer. Segmenting nuclei is the initial phase in the analysis of microscopic images, as it directly influences the outcomes. This task is very challenging because the image acquisition is associated with color variation which is due different the use of different staining methods [1], artifacts, large variation in size, shape and texture of the cell nuclei [2], touching and overlapping nuclei [3], which is an obstacle for computer-aided diagnosis (CAD) segmentation algorithms. Numerous investigations have concentrated on nuclei detection because of its importance in the diagnosis of cancer. while traditional image processing approaches are being utilized for this task, could not achieve optimized performance due to inherent diversity involved within the images [4]. Past decade has witnessed a substantial progress in deep learning. Techniques relying on deep neural networks have attained state-of-art performance in automatic medical image segmentation [5]. These methods have demonstrated superior outcomes compared to traditional approaches, showcasing the capability of harnessing deep learning techniques for the task of medical image segmentation.

Numerous studies have explored deep learning architectures for cell nuclei segmentation, each presenting unique methods and approaches to address this critical challenge. Despite these advancements, the demand for more precise nuclei segmentation persists. The rapid evolution of deep learning in the domain of medical image analysis has led to the development of various approaches, with many relying on the U-Net architecture [11], which has become the standard for medical image segmentation. Training exceptionally deep architectures introduces challenges that are primarily related to the problem of vanishing gradients. However, due to low resolution and blurry boundary of medical images, it is still a challenging task to design new models that can effectively capture more fine-grained details. In light of the ongoing need for more accurate nuclei segmentation, inspired by the success of U-Net [11] and deep residual learning [21], we propose Deep Residual U-Net that combines the strengths of residual learning and the U-Net architecture. This integration simplifies the training process, ensures smooth information propagation through the use of skip connections and mitigate the issue of vanishing gradients.

The significance of the Deep Residual U-Net is described below:

- Propose Deep Residual U-Net for semantic segmentation. This approach integrates deep residual network with standard U-net architecture to extract robust discriminative features from the input images.

- The evaluation of this proposed model on publicly available microscopy image dataset, specifically the 2018 Data Science Bowl grand challenge, has revealed notable improvements in various performance metrics.

- Proposed model achieves better segmentation masks in comparison with other baseline models, the especially in complex images with diverse cell sizes and shapes, where overlapping nuclei are prevalent.

Rest of the paper is organized as follows: Section II provides an overview of the related work in the field of nuclei segmentation. In Section III, we describe the overall methodology. Section IV describes the dataset, evaluation metrics and the experimental setup used for experimentation. In Section V, the results obtained and the performance

evaluation is discussed. In the last, we summarize the paper and discuss the future work.

## II. RELATED WORK

Numerous deep learning architectures have been proposed for cell nuclei segmentation. Song et al. [6] introduced an approach based on CNN to segment cervical nuclei and cytoplasm. Their methodology involved in employing a CNN for nuclei detection, followed by coarse segmentation based on Sobel edge operator, morphological operations and thresholding. Xing et al. [7] generated probability maps for nuclei by applying Two-class CNN to digitized histopathology images. And to address the challenge of overlapping nuclei, the robust shape model (dictionary of nuclei shapes) was constructed and repulsive deformable model at local level was utilized. Kumar et al. [8] proposed Three-class CNN to predict the nuclei, background, and the boundary of each nucleus. This approach yielded notably better outcomes when compared to Two-class problem but the post-processing step was time consuming. The first FCN for semantic segmentation was presented by Long et al. [9]. Their results showed that the FCN can achieve state-of-the art performance in the realm of segmentation. Further, the inference step associated with this method is significantly faster to obtain the corresponding segmentation mask. For the task of nuclei segmentation in histopathology images, Naylor et al. [10] used FCN to obtain the nuclei probability map, then watershed method was applied to split the touching nuclei, but when comparing the nuclei boundaries predicted by this approach to the ground truth images was not accurate.

Investigation in the domain of deep learning is increasing rapidly, development of new architectures is under process at significantly fast speed. Accounting the importance of cell nuclei segmentation, several approaches have been proposed to address this issue, most of them are relying on U-Net [11]. U-Net is the prevailing architecture used for medical image segmentation. Several approaches based on U-Net have been presented to resolve the issue of nuclei segmentation. Cui et al. [12] have proposed a method, inspired by U-Net, to predict nuclei and their contours simultaneously in H&E-stained images. By predicting contour of each nucleus, applying a sophisticated weight map in the loss function they were able to split touching and overlapping nuclei accurately with simple and parameter free post-processing step. Caicedo et al. [4] trained U-Net model to predict the nuclei and their boundaries, giving the loss function with weight which is 10 times more to the boundary class. The first best solution by [ods.ai] topcoders [13], used encoder-decoder type architecture based on U-Net, initializing encoders with pretrained weights. Kong et al. [14] have used Two-stage stacked U-Nets, where stage1 for nuclei segmentation and stage2 to tackle the problem of overlapping nuclei. Zhao et al. [15] used U-Net++, which is a modification to the U-Net [11] architecture, which combined U-Nets of different depths. Pan et al. [16] proposed AS-Unet, an extension of the U-Net architecture, is structured around three fundamental components: encoder module, decoder module and an atrous convolutional module. Alom et al. [17] applied a technique which relied on the RCNN for nuclei segmentation tasks. J. Cheng et al. [18] used FCANet, which is based on U-Net that captures long-range and short-range

distance features and use attention module to refine the features. Chen et al. [19] proposed Dense-Res-Inception Net (DRINET) for the task of segmentation on medical images and compared their results with FCN, U-Net and ResUNet. Ibtehaz et al. [20] enhanced the U-Net architecture and proposed an advanced MultiResUNet architecture for medical image segmentation. They conducted comprehensive comparison with U-Net using diverse medical image segmentation datasets, revealing that their proposed method achieved enhanced accuracy compared to U-Net.

From the aforementioned review of relevant studies, it is evident that there have been substantial efforts invested in the advancement of deep Convolution Neural Networks (CNN) architectures in effectively segmenting both natural and medical images. Recent research has indicated that better performance can achieved through deeper network. However, training exceptionally deep architectures poses the challenges due to the issue of vanishing gradients. To handle this problem, He et al. [21] proposed the deep residual learning framework to facilitate the training process by utilizing an identity mapping [22]. Instead of using skip connection in Fully Convolutional Networks (FCNs) [9], Ronneberger et al. [11] proposed U-Net that amalgamate feature maps from various hierarchical levels, resulting in enhanced segmentation accuracy. By merging low-level intricate details and high-level semantic insights, U-net has demonstrated remarkable performance in biomedical image segmentation tasks [11]. Inspired by deep residual learning [21] and U-Net [11], we have integrated the residual network to the U-Net architecture. This integration allows us to harness the strengths of both residual learning and U-Net framework, resulting in a unified approach that maximizes the benefits derived from each approach. We have replaced plain neural units by residual units in the U-Net architecture which simplifies the training process and incorporation of robust skip connections within the network has enabled the smooth propagation of information without experiencing degradation.

## III. METHODOLOGY

### A. Overview of Deep Residual U-Net Architecture

- *U-Net*: Semantic segmentation is a task of dividing an image into segments or regions, where each segment corresponds to a meaningful object or part of a scene. In semantic segmentation, utilization of low-level details while preserving high-level semantic information [9, 11] holds immense significance, as it is crucial in attaining precise results. However, especially when we are with limited training samples, training such deep neural networks becomes very challenging. Two possible ways to address this problem. First, by using a pre-trained network later fine-tuning it on the target dataset as in [9]. Two, by utilizing data augmentation strategy which is done in U-Net [11]. Along with the data augmentation, we believe that U-Net architecture also contributes to alleviate the training problem. The idea behind this is that, copying low level features to its equivalent high levels creates a path to propagate information which allows signal to propagate seamlessly between low levels and high

levels by facilitating backward propagation during training process and also compensating low level finer details to its corresponding high level semantic features. This concept pertains to residual neural network [21].

- Residual unit: Adding more layers can improve the performance of the multi-layer neural network by increasing the trainable parameters which may lead to redundant computation and may cause degradation problem [21]. To handle this problem, He et al. [21] proposed the deep residual learning framework, aiming to alleviate training difficulties and effectively mitigate the degradation problem. This leads to improvement in network's performance without the need for deeper network or pre-trained networks. A deep residual network comprises a sequence of layered residual blocks, with each individual residual block is defined as:

$$y_i = h(x_i) + F(x_i, W_i), \quad (1)$$

$$x_{i+1} = f(y_i) \quad (2)$$

Where $x_i$ is the input and $x_{i+1}$ output of the ith residual block, $F(.)$ is the residual function, $f(y_i)$ is the activation function, $h(x_i)$ represents the identity mapping function and $W_i$ is the weight vector of the feature map within the ith residual block. The difference between plain neural unit and residual block illustrated in Fig. 1. Within each residual block, a composition of batch normalization (BN), ReLu activation function and convolution layers is present. He at el. [22] has discussed the impacts on using different combinations and suggested the full pre-activation design as depicted in Fig. 1(b). In our work, we have used full pre-activation residual block to build our deep residual U-Net.

- Deep Residual U-Net: Here we propose a deep residual U-Net, a neural network designed for semantic segmentation which takes the advantage of both U-Net and residual neural network. With this combination, the residual blocks in the network contributes to smoother training process and the skip connections within these blocks, as well as between the network's low levels and high levels ensures smooth flow of information without degradation. Also, it allows to design the neural network with relatively few parameters and could achieve comparable better performance in semantic segmentation tasks.

In this study, we have utilized 9-level architecture of deep residual U-Net for nuclei segmentation as depicted in Fig. 2. The network consists three parts: Encoding, Bridge and Decoding paths. The first part, involves in capturing high level features from the input image by reducing its spatial dimensions while preserving the important spatial information through skip connections. The last part, involves in upsampling the encoded feature maps to reconstruct the segmentation mask with the same spatial resolution as that of the input image. The middle part, serves as a bridge in connecting the encoding path and decoding path. All segments are constructed using residual blocks, each comprising two 3×3 convolutional blocks and an identity mapping. Each convolutional block has a BN layer, a ReLu activation layer and a convolution layer in it. The identity mapping connects both input and output of the block.

The encoder path has four residual blocks. In each block, to downsample the feature map size, instead of using maxpooling operation, a stride of 2 is implemented on the first convolution block to reduce the feature map by half. Likewise, the decoder pathway comprises four residual blocks. Every residual block entails the upsampling of feature maps from lower levels, coupled with the concatenation of feature maps derived from the corresponding encoder path. Finally, 1×1 convolution layer is employed succeeded by a sigmoid activation layer. The role of sigmoid activation function is to project the multi-channel feature maps into the intended segmentation map. Overall, the network encompasses 28 convolution layers. The parameters and the resultant output sizes of each step are provided in Table I.
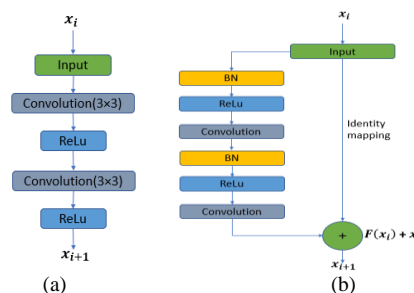


Fig. 1. Building blocks of neural networks. (a) Plain neural unit used in U-net and (b) residual block with identity mapping used in the proposed deep residual U-Net.
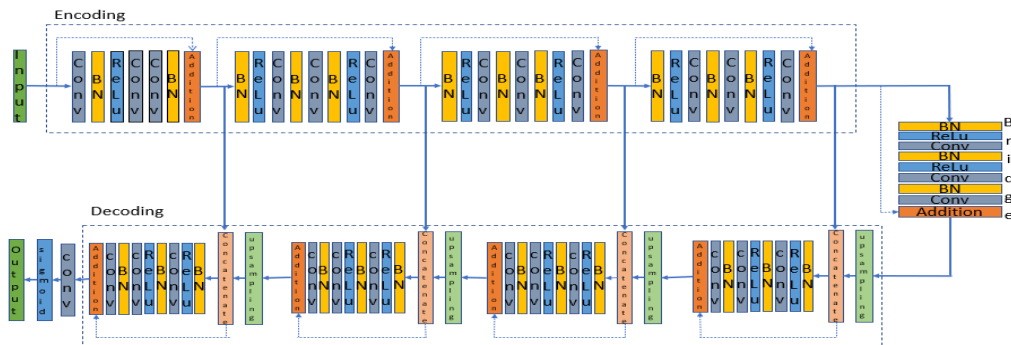


Fig. 2. The architecture of deep residual U-Net.

TABLE I.    THE NETWORK STRUCTURE OF DEEP RESIDUAL U-NET

| | Level | Conv Layer | Filter | Stride | Output Size |
|---|---|---|---|---|---|
| **Input** | | | | | $256 \times 256 \times 3$ |
| **Encoding** | Level 1 | Conv 1 | $3 \times 3/16$ | 1 | $256 \times 256 \times 16$ |
| | | Conv 2 | $3 \times 3/16$ | 1 | $256 \times 256 \times 16$ |
| | | Conv 3 | $3 \times 3/16$ | 1 | $256 \times 256 \times 16$ |
| | Level 2 | Conv 4 | $3 \times 3/32$ | 2 | $128 \times 128 \times 32$ |
| | | Conv 5 | $3 \times 3/32$ | 1 | $128 \times 128 \times 32$ |
| | | Conv 6 | $3 \times 3/32$ | 1 | $128 \times 128 \times 32$ |
| | Level 3 | Conv 7 | $3 \times 3/64$ | 2 | $64 \times 64 \times 64$ |
| | | Conv 8 | $3 \times 3/64$ | 1 | $64 \times 64 \times 64$ |
| | | Conv 9 | $3 \times 3/64$ | 1 | $64 \times 64 \times 64$ |
| | Level 4 | Conv 10 | $3 \times 3/128$ | 2 | $32 \times 32 \times 128$ |
| | | Conv 11 | $3 \times 3/128$ | 1 | $32 \times 32 \times 128$ |
| | | Conv 12 | $3 \times 3/128$ | 1 | $32 \times 32 \times 128$ |
| **Bridge** | Level 5 | Conv 13 | $3 \times 3/256$ | 2 | $16 \times 16 \times 256$ |
| | | Conv 14 | $3 \times 3/256$ | 1 | $16 \times 16 \times 256$ |
| | | Conv 15 | $3 \times 3/256$ | 1 | $16 \times 16 \times 256$ |
| **Decoding** | Level 6 | Conv 16 | $3 \times 3/128$ | 1 | $32 \times 32 \times 128$ |
| | | Conv 17 | $3 \times 3/128$ | 1 | $32 \times 32 \times 128$ |
| | | Conv 18 | $3 \times 3/128$ | 1 | $32 \times 32 \times 128$ |
| | Level 7 | Conv 19 | $3 \times 3/64$ | 1 | $64 \times 64 \times 64$ |
| | | Conv 20 | $3 \times 3/64$ | 1 | $64 \times 64 \times 64$ |
| | | Conv 21 | $3 \times 3/64$ | 1 | $64 \times 64 \times 64$ |
| | Level 8 | Conv 22 | $3 \times 3/32$ | 1 | $128 \times 128 \times 32$ |
| | | Conv 23 | $3 \times 3/32$ | 1 | $128 \times 128 \times 32$ |
| | | Conv 24 | $3 \times 3/32$ | 1 | $128 \times 128 \times 32$ |
| | Level 9 | Conv 25 | $3 \times 3/16$ | 1 | $256 \times 256 \times 16$ |
| | | Conv 26 | $3 \times 3/16$ | 1 | $256 \times 256 \times 16$ |
| | | Conv 27 | $3 \times 3/16$ | 1 | $256 \times 256 \times 16$ |
| **Output** | | Conv 28 | $1 \times 1$ | 1 | $256 \times 256 \times 1$ |

## IV. EXPERIMENTS

*Within* this section, we delve into the details of the dataset, the evaluation metrics, the experimental setup and the data augmentation techniques utilized to validate our proposed model.

### A. Dataset

In our research, we utilized the dataset provided by Kaggle 2018 DSB challenge. The dataset includes 871 images with 37, 333 manually annotated nuclei. The images represent 31 experiments with 22 cell types, 15 different resolutions and 5 groups of images which are visually indistinguishable. This dataset includes 2D light microscopy images with different staining methods including DAPI, Hoechst or H&E and cells of different sizes which display the structures from variety of organs and animal model. Out of 31 experiments, 16 are for training (670 samples), first-stage evaluation (65 samples) and 15 for second-stage evaluation (106 samples). This dataset is readily accessible to the public through the Broad Bioimage Benchmark Collection.

The dataset comprises of 670 training samples accompanied by their corresponding masks. For our experiments, we have allocated 80% of the dataset for training

purpose, while 10% for validation and remaining 10% was reserved for testing. Additionally, we have evaluated our trained model on stage1_test dataset provided by the challenge. This dataset comprises of 65 samples, each equipped with ground truth masks.

### B. Evaluation Metrics

The evaluation of the proposed model is based on several metrics, including the Sørensen–Dice coefficient (DSC), also referred to as F1-Score, the Intersection over Union (IoU), commonly known as the Jaccard Index (JI), Precision and Recall. DSC assesses the similarity between predicted and ground truth masks, while IoU quantifies the overlap between the two masks, Precision measures the portion of pixels that are correctly classified as nuclei pixels out of all the pixels that are classified as nuclei pixels and Recall measures the portion of pixels that are correctly classified as nuclei pixels out of all the pixels that are actually nuclei pixels in the image. These indices are expressed in equations (3-6). The terms TP, FP, TN and FN correspond to True positive, False positive, True negative and False negative [16].

$$\text{Precision} = \frac{TP}{TP+FP} \qquad (3)$$

$$\text{Recall} = \frac{TP}{TP+FN} \quad (4)$$

$$\text{Dice coefficient (DSC)} = \frac{2TP}{2TP+FP+FN} \qquad (5)$$

$$\text{IoU} = \frac{TP}{TP+FP+FN} \quad (6)$$

### C. Experimental Setup

The proposed model is implemented using Keras framework [23] with Tensorflow 2.7.0 as backend, OpenCV library and python 3.7. The number of kernels in the encoder were set to 16, 32, 64, 128 and 256, and the kernels in the decoder were set to 128, 64, 32, 16 and 1. The input images were resized to dimensions of $256 \times 256$ pixels. We have employed binary cross-entropy as the loss function and an Adam optimization technique, aiming to minimize the loss function with the batch size of 16 and a learning rate of 1e-4. A training procedure was conducted for a span of 100 epochs, with criteria such as early stopping and ReduceLROnPlateau. To prevent the model overfitting, data augmentation techniques such as horizontal flipping, rotation and zooming has been adopted on training dataset in our experiment. The experiment was performed on Nvidia GeForce RTX2080 Ti with 11GB RAM.

## V. RESULTS AND DISCUSSION

Within this section, we present the results and compare with state-of-art methods. U-Net is still considered as baseline for diverse medical image segmentation tasks. In the interest of comprehensive comparison, we also trained U-Net, U-Net++ and HR-Net which are well-regarded techniques for nuclei segmentation with the same experimental setup. The learning curve of our proposed model is presented in Fig. 3. Notably, our model demonstrates the convergence after 30 epochs, exhibiting a validation loss of 0.069 and IoU score of 0.8213, respectively.
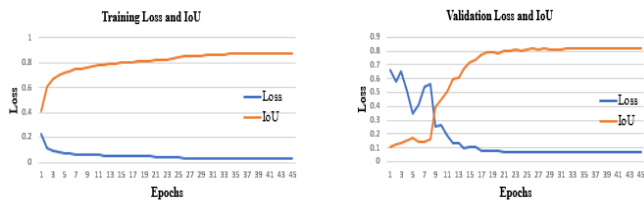
Fig. 3. Loss v/s IoU curve of training (left-side) and validation (right-side) trained on our proposed model.

Fig. 4 depicts the loss curve during training and validation process. When we observe the curve during training, the loss value is decreasing after each epoch. During validation, the loss value reduces unevenly and later it becomes smooth.
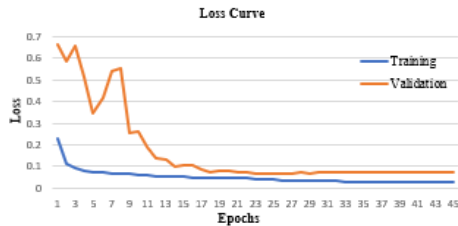


Fig. 4. Training v/s validation loss curve.

Fig. 5 illustrates a comparative analysis of our proposed model in contrast to other baseline models in terms of loss values and IoU scores throughout training and validation phases. In Fig. 5(a), which portrays training loss curve, as well as in Fig. 5(b) which depicts validation loss curve, the loss value of our proposed model is lowest during training and remains competitive with other models during validation process. Fig. 5(c) shows the IoU curve obtained during training and Fig. 5(d) shows the IoU curve observed during validation for all the models. It is evident from Fig. 5(c) and 5(d), our proposed model attains a better IoU in comparison to other models during both training and validation process. Notably, U-Net has achieved the lowest IoU, while U-Net++ and HR-Net yield nearly identical IoU scores. Overall, from Fig. 5, our proposed model showcases better performance when compared to other models.
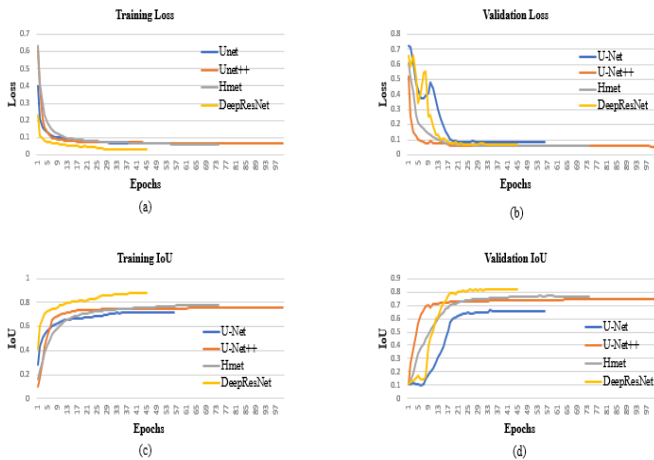


Fig. 5. Comparison of loss curve and IoU curve of our proposed model with other models during training and validation process. (a)Training loss, (b) validation loss, (c) Training IoU and (d) Validation IoU.

The outcomes of our proposed method are presented in Table II alongside those of baseline methods, assessed using various evaluation metrics. It is evident that our proposed method surpasses the initial U-Net [11] by 1.77% in DSC and 1.09% in IoU. Furthermore, when compared with U-Net++ [15] and HR-Net [24], our method showcases substantial improvement across DSC, IoU and Precision metrics. The recall of the U-Net++ has a slight increase of 0.01% compared to U-Net.

TABLE II. QUANTITATIVE RESULTS ON THE EXPERIMENTAL DATASET WITH BASELINE METHODS

| *Model* | *Accuracy* | *DSC* | *IoU* | *Recall* | *Precision* |
|---|---|---|---|---|---|
| U-Net [11] | 0.978±0.021 | 0.908±0.087 | 0.842±0.121 | 0.911±0.113 | 0.917±0.087 |
| U-Net++ [15] | **0.979±0.022** | 0.898±0.074 | 0.827±0.110 | **0.912±0.105** | 0.895±0.065 |
| HR-Net [24] | 0.967±0.028 | 0.852±0.121 | 0.757±0.142 | 0.880±0.136 | 0.836±0.146 |
| **DeepRes Net** | 0.977±0.022 | **0.910±0.102** | **0.853±0.126** | 0.911±0.115 | **0.918±0.084** |

The comparison of our proposed method with other state-of-art techniques is summarized in Table III. The data within the table clearly underscores better performance of our model in relation to other methods.

TABLE III. QUANTITATIVE RESULTS ON THE EXPERIMENTAL DATASET WITH STATE-OF-ART METHODS

| Model | Accuracy | DSC | IoU | Recall | Precision |
|---|---|---|---|---|---|
| SegNet [25] | -- | 0.738±0.134 | 0.620±0.135 | -- | 0.820±0.132 |
| DeepLabV3+ [26] | -- | 0.741±0.319 | 0.674±0.260 | -- | 0.818±0.401 |
| DANet [27] | -- | 0.616±0.161 | 0.564±0.300 | -- | 0.761±0.126 |
| FCANet [18] | -- | 0.897±0.080 | 0.814±0.136 | -- | 0.895±0.051 |
| DoubleU-Net [28] | 0.941±0.068 | 0.903±0.089 | 0.833±0.129 | 0.865±0.131 | 0.957±0.039 |
| MSAU-Net [29] | 0.944±0.066 | 0.907±0.039 | 0.842±0.128 | 0.893±0.122 | 0.938±0.069 |
| TransU-Net [30] | 0.954±0.047 | 0.895±0.099 | 0.821±0.136 | 0.906±0.121 | 0.900±0.101 |
| OAU-Net [31] | 0.9677 | 0.8992 | 0.8235 | 0.9008 | 0.9096 |
| DeepResNet | 0.977±0.022 | 0.910±0.102 | 0.853±0.126 | 0.911±0.115 | 0.918±0.084 |

Fig. 6 displays the segmentation outcomes of each model. Through visual examination, it becomes apparent that the segmentation mask generated by our model is better than those produced by other models.

Our proposed model, along with other models, underwent testing and evaluated using stage1_test dataset which includes 65 samples, each accompanied by a ground truth mask provided by the organizers. Quantitative outcomes on

stage1_test dataset, comparing our proposed method to other techniques are tabulated in Table IV across various evaluation metrics. Upon inspecting Table IV, it apparent that our model surpasses the original U-Net by 5.8% in DSC and 6.0% in IoU.
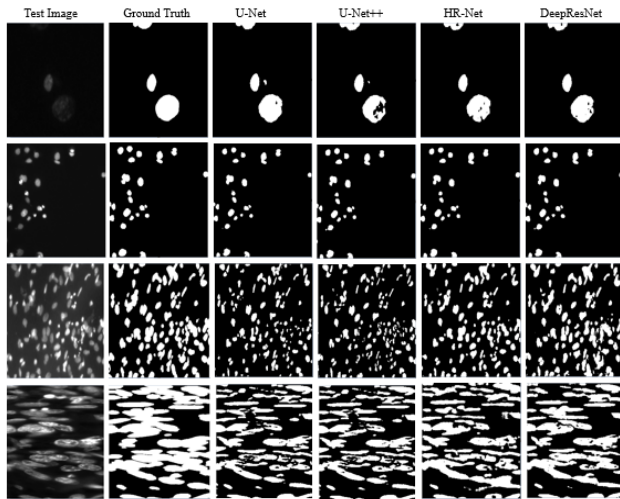


Fig. 6. Visualization of segmentation results on test dataset.

TABLE IV. QUANTITATIVE RESULTS ON THE STAGE1_TEST DATASET

| Model | Accuracy | DSC | IoU | Recall | Precision |
|---|---|---|---|---|---|
| U-Net [11] | 0.932±0.075 | 0.780±0.211 | 0.679±0.234 | 0.739±0.243 | 0.904±0.149 |
| U-Net++ [15] | 0.943±0.056 | 0.826±0.140 | 0.724±0.172 | 0.790±0.176 | 0.892±0.140 |
| HR-Net [24] | 0.941±0.063 | 0.824±0.150 | 0.724±0.179 | 0.803±0.167 | 0.869±0.163 |
| DeepRes Net | 0.946±0.053 | 0.838±0.129 | 0.739±0.162 | 0.817±0.150 | 0.886±0.145 |

Notably, the model's precision (0.886) falls short of that achieved by U-Net++. However, recall rate remains competitive when compared to other models. Overall, our model demonstrates strong performance across multiple metrics.

To visualize the segmentation outcomes in detail, we examine samples from test set that encompass cells of varying sizes. The qualitative comparison between ground truth images, our proposed model and other models on stage1_test dataset is depicted in Fig. 7. In the Fig. 7, the first column represents the actual image, second column displays its corresponding ground truth mask and remaining columns represents the prediction masks of different models. Among the prediction masks, the red represents the part where the model predicts the background as the target area (FP). For the microscopic images with few of cells, where the nuclei can easily be discriminated from the background, all the models demonstrate satisfactory segmentation outcomes. However, for the complex images such as third, fourth and fifth rows of images with nuclei of different sizes and shapes, the segmentation mask produced by our model is better than those of other models. Also, our model exhibits fewer false positives and enhanced detection accuracy in comparison to the other models.
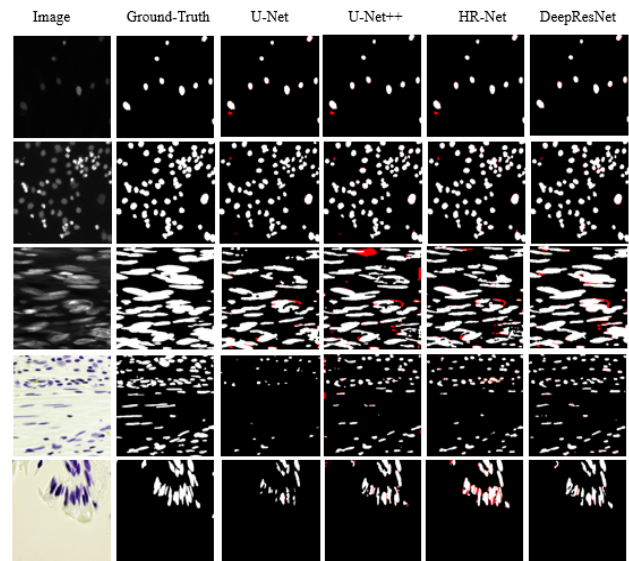


Fig. 7. Visualization of segmentation results on stage1_test dataset.

## VI. CONCLUSION

Addressing the requirement for more precise nuclei segmentation task, we propose a semantic segmentation neural network that harnesses the combined strength of residual learning and U-Net. The residual block within the network makes the training process easier, while the skip connections within and between the residual block at low and high levels of the network will propagate the information both in forward and backward computations. Also, this property allows us design a simple powerful neural network with fewer number of parameters compared to U-Net. Our model's efficacy was evaluated on publicly available microscopy image dataset from 2018 Data Science Bowl grand challenge. The outcomes of our experiments revealed an average IoU improvement of 1.1 and 5.8 (for the stage1_test set) over original U-Net. Across images with smaller number of cells, where nuclei were distinct, all models performed well. However, when faced with complex images containing cells of diverse sizes and shapes, our proposed model consistently generated better segmentation masks compared to its counterparts. The evaluation conclusively demonstrates that our model excels in terms of accuracy, precision, recall and dice-coefficient when compared to U-Net and other prominent models.

Subsequently, we incorporated watershed segmentation as a post-processing step to tackle the challenges associated with touching nuclei and overlapping/clustered nuclei. This approach proved successful in effectively segmenting touching nuclei. In the future, we plan to conduct experimentation on larger and more diverse dataset that can help validate our model's performance and generalizability. Further, we continue to explore and develop most effective post-processing methods to address the challenge of overlapping nuclei.

REFERENCES

[1] Khoshdeli, M., and Parvin, B.: Deep leaning models delineates multiple nuclear phenotypes in H&E-stained histology sections, arXiv preprint arXiv:1802.04427, (2018).

[2] Liu, Y., Zhang, P., Song, Q., Li, A., Zhang, P., Gui, Z.: Automatic segmentation of cervical nuclei based on deep learning and a conditional random field, IEEE Access, vol. 6, pp. 53 709–53 721, (2018). doi: 10.1109/ACCESS.2018.2871153

[3] Xing, F., Xie, Y., Yang, L.: An automatic learning-based framework for robust nucleus segmentation, IEEE transactions on medical imaging, Feb;35(2):550-66, (2016). doi: 10.1109/TMI.2015.2481436

[4] Caicedo, J. C., Roth, J., Goodman, A., Becker, T., Karhohs, K. W, Broisin, M., Csaba, M., McQuin, C., Singh, S., Theis, F. et al. "Evaluation of deep learning strategies for nucleus segmentation in fluorescence images," BioRxiv, p. 335216, (2019). doi: 10.1002/cyto.a.2386

[5] Litjens, G., Kooi, T., Bejnordi, B.E., Setio, A. A. A., Ciompi, F., Ghafoorian, M., Van Der Laak, J. A., Van Ginneken, B., C. I. S´anchez. A survey on deep learning in medical image analysis, Medical image analysis (MedIA), vol. 42, pp. 60–88, (2017).

[6] Song, Y., Zhang, L., Chen, S., Ni, D., Li, B., Zhou, Y., Lei, B., Wang, T.: A deep learning based framework for accurate segmentation of cervical cytoplasm and nuclei, Engineering in Medicine and Biology Society (EMBC), 36th annual international conference of the IEEE, IEEE, pp. 2903–2906, (2014). doi: 10.1109/EMBC.2014.6944230

[7] Xing, F., Xie, Y., Yang, L.: An automatic learning-based framework for robust nucleus segmentation, IEEE transactions on medical imaging, Feb;35(2):550-66, (2016). doi: 10.1109/TMI.2015.2481436

[8] Kumar, N., Verma, R., Sharma, S., Bhargava, S., Vahadane, A., Sethi, A.: A dataset and a technique for generalized nuclear segmentation for computational pathology, IEEE transactions on medical imaging, vol. 36, no. 7, pp. 1550–1560, (2017). doi: 10.1109/TMI.2017.2677499

[9] Long, J., Shelhamer, E., Darrell, T.: Fully convolutional networks for semantic segmentation, Proceedings of the IEEE conference on computer vision and pattern recognition, pp. 3431–3440, (2015). doi: 10.1109/TPAMI.2016.2572683

[10] Naylor, P., Lae, M., Reyal, F., Walter, T.: Nuclei segmentation in histopathology images using deep neural networks, 14th International Symposium on Biomedical Imaging (ISBI 2017). IEEE, pp. 933–936, (2017). doi: 10.1109/ISBI.2017.7950669

[11] Ronneberger, O., Fischer, P., Brox, T.: U-net: Convolutional networks for biomedical image segmentation, International Conference on Medical image computing and computer-assisted intervention. Springer, pp. 234–241, (2015). doi: 10.1007/978-3-319-24574-4_28

[12] Cui, Y., Zhang, G., Liu, Z., Xiong, Z., Hu, J.: A deep learning algorithm for one-step contour aware nuclei segmentation of histopathological images, arXiv preprint arXiv:1803.02786, (2018). doi: 10.1007/s11517-019-02008-8

[13] [ods.ai] topcoders, 1st place solution, https://www.kaggle.com/c/data-science-bowl-2018/discussion/54741

[14] Yan, K., Georgi, Z. G., Wang, X., Zhao, H., Lu, H.: Nuclear segmentation in Histopathological Images using Two-Staged Stacked U-Nets with Attention Mechanism, Front. Bioeng. Biotechnol., 26 October (2020). doi: 10.3389/fbioe.2020.573866

[15] Zhou, Z., Siddiquee, M. M. R., Tajbakhsh, N., Liang, J.: UNet++: Redesigning Skip Connections to Exploit Multiscale Features in Image Segmentation, IEEE Transactions on Medical Imaging, vol. 39, no. 6, pp. 1856-1867, June (2020). doi: 10.1109/TMI.2019.2959609

[16] Pan, X., Li, L., Yang, D., He, Y., Liu, Z., Yang, H.: An Accurate Nuclei Segmentation Algorithm in Pathological Image Based on Deep Semantic Network, IEEE Access, vol. 7, pp. 110674-110686, (2019). doi: 10.1109/ACCESS.2019.2934486

[17] Alom, MZ., Yakopcic, C., Hasan, M., Taha, TM., Asari, VK.: Recurrent residual U-Net for medical image segmentation, J. Med. Imag. 6(1), 014006 (2019), doi: 10.1117/1.JMI.6.1.014006

[18] Cheng, J., Tian, S., Yu, L., Lu, H., Lv, X.: Fully convolutional attention network for biomedical image segmentation, Artificial Intelligence in Medicine 107 (4):101899, June (2020). doi: 10.1016/j.artmed.2020.101899

[19] Chen, L., Bentley, p., Mori, K., Misawa, K., Fujiwara, M., Rueckert D.: Drinet for medical image segmentation, IEEE transactions on medical imaging, vol. 37, no. 11, pp. 2453–2462, (2018).

[20] Ibtehaz, N., Rahman, MS.: Multiresunet: Rethinking the u-net architecture for multimodal biomedical image segmentation, Neural Networks, vol. 121, pp. 74–87, (2020). doi: 10.1109/TMI.2018.2835303

[21] He, K., Zhang, H., Ren, S., Sun, J.: Deep residual learning for image recognition, in CVPR, pp. 770–778, (2016). doi: 10.1109/CVPR.2016.90

[22] He, K., Zhang, H., Ren, S., Sun, J.: Identity mappings in deep residual networks, in ECCV, pp. 630–645, (2016). arXiv:1603.05027v3

[23] Chollet F, et al. Keras: The python deep learning library 2015; 2019.

[24] Wang, J., Sun, K., Cheng, T., Jiang, B., Deng, C., Zhao, Y., Liu, D., Mu, Y., Tan, M., Wang, X., Liu, W., Xiao, B. Deep High-Resolution Representation Learning for Visual Recognition, IEEE Transactions on Pattern Analysis and Machine Intelligence, vol. 43, pp. 3349-3364, Oct. (2021). doi: 10.1109/TPAMI.2020.2983686

[25] Badrinarayanan, V., Kendall, A., Cipolla, R. Segnet: A deep convolutional encoderdecoder architecture for image segmentation. IEEE Trans Pattern Anal Mach Intell 2017;39(12):2481–95. https://doi.org/10.17863/CAM.17966.

[26] Chen L, Zhu Y, Papandreou G, et al. Encoder-decoder with atrous separable convolution for semantic image segmentation. Proceedings of the European Conference on Computer Vision (ECCV) 2018:833–51. https://doi.org/10.1007/978-3-030-01234-2_49

[27] Fu J, Liu J, Tian H, et al. Dual attention network for scene segmentation. Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition 2019:3146–54. https://doi.org/10.1109/CVPR.2019.00326.

[28] Jha D, Riegler MA, Johanseny D, Halvorsen P, Johanseny HD, Met S (2006) Double U-Net: a deep convolutional neural network for medical image segmentation. Electr Eng Syst Sci—Image Video Process, Cornell Univ, June (2020). https://doi.org/10.1109/CBMS49503.2020.00111

[29] Xu, Q., Duan, W. An Automatic Nuclei Image Segmentation Based on Multi-Scale Split-Attention U-Net, Proceedings of the MICCAI Workshop on Computational Pathology, PMLR 156:236-245, (2021).

[30] Chen J., Lu Y., Yu Q., Luo X., Adeli E., Wang Y., Lu L., Yuille A.L., Z hou Y. Transunet: Transformers make strong encoders for medical image segmentation (2021). arXiv preprint arXiv:2102.04306

[31] Song H., Wang Y., Zeng S., Guo X., Li Z. OAU-Net: Outlined Attention U-net for biomedical image segmentation, Biomedical Signal Processing and Control, Volume 79, January (2023). https://doi.org/10.1016/j.bspc.2022.104038

# Diabetes Prediction Empowered with Multi-level Data Fusion and Machine Learning

Ghofran Bassam[1], Amina Rouai[2], Reyaz Ahmad[3], Muhammd Adnan Khan[4]

School of Computing, Skyline University College, Sharjah, United Arab Emirates[1, 2, 4]
Department of General Education, Skyline University College, Sharjah, United Arab Emirates[3]
Riphah School of Computing & Innovation-Faculty of Computing, Riphah International University, Lahore, Pakistan[4]
Department of Software-Faculty of Artificial Intelligence and Software, Gachon University, Seongnam-si, Republic of Korea[4]

*Abstract*—**Technology improvements have benefited the medical industry, especially in the area of diabetes prediction. In order to find patterns and risk factors related to diabetes, machine learning and Artificial Intelligence (AI) are vital in the analysis of enormous volumes of data, including medical records, lifestyle variables, and biomarkers. This makes it possible for tailored management and early discovery, which might revolutionize healthcare. This study examines how machine learning algorithms may be used to identify diseases, with an emphasis on diabetes prediction. The Proposed Diabetes Prediction Empowered with Mutli-level Data Fusion and Machine Learning (DPEMDFML) model combines two distinct types of models—the Artificial Neural Network (ANN) and the Support Vector Machine (SVM)—to create a fused machine learning technique. Two separate datasets were utilized for training and testing the model in order to assess its performance. To ensure a thorough evaluation of the model's prediction ability, the datasets were split in two experiments in proportions of 70:30 and 75:25, respectively. The study's findings were encouraging, with the ANN algorithm obtaining a remarkable accuracy of 97.43%. This indicates that the model accurately identified instances of diabetes, indicating a high degree of accuracy. A more thorough knowledge of the model's prediction ability would result from further assessment and validation of its performance using various measures.**

*Keywords—Disease prediction; machine learning (ML); fused approach; artificial neural network (ANN); support vector machine (SVM); disease diagnosis; healthcare*

## I. INTRODUCTION

The chronic metabolic condition known as diabetes affects millions of people worldwide. The World Health Organization projects that by 2030, 643 million people worldwide will have diabetes, up from an expected 537 million in 2021 [1]. Diabetes is brought on by abnormalities in insulin synthesis or function, which hinder the body from effectively managing blood sugar levels. All ages are impacted, and if it is not treated, it might have detrimental implications on one's health. The body's immune system wrongly assaults and destroys pancreatic insulin-producing cells in autoimmune type 1 diabetes [2]. It usually appears during childhood or adolescence and necessitates lifelong insulin medication. Obesity, inactivity, and poor eating habits are commonly linked to the majority of type 2 diabetes cases [3]. Type 2 diabetes is differentiated by a decrease in the body's ability to produce enough insulin to maintain normal blood sugar levels or by an increase in insulin resistance [3]. Numerous

consequences can result from unmanaged diabetes. For diabetics, cardiovascular disease, such as heart attacks and strokes, is a major worry. Kidney issues, nerve damage (neuropathy), retinopathy, and foot issues are some of the consequences of diabetes [4]. One's quality of life may be significantly impacted by these problems, which need continual medical care. Traditional diabetes prediction systems confront a number of problems. These techniques frequently depend on simplistic statistical models or rudimentary machine learning algorithms, which are incapable of capturing the intricate interplay of many risk variables. Furthermore, these techniques may underutilize the potential of accessible data sources such as patient medical records, genetic information, lifestyle variables, and environmental factors. As a result, the accuracy and reliability of diabetes prediction using these traditional methods are inadequate. A subset of artificial intelligence called machine learning has completely changed several industries, including the healthcare industry. It involves developing algorithms and models that are able to absorb knowledge from data and act or anticipate without being explicitly programmed. The medical sector's decision-making processes for disease prediction, diagnosis, and treatment have showed great promise when using machine learning techniques. Researchers have investigated the merging of different ML methods for diabetes prediction in order to overcome the limitations of existing methodologies (Table I). Fusing several algorithms enables for the use of each method's distinct strengths while correcting for their particular flaws and improving forecast accuracy. A fused machine learning model can give a more thorough and holistic view of the condition by merging diverse data sources such as electronic health records, medical imaging, genetic profiles, and lifestyle data [5]. An ML-based diagnostic system can help detect diabetic patients early on which leads improve patient outcomes and help lessen the burden of diabetes on individuals and healthcare systems. This paper presents a unique framework utilizing machine learning fusion to achieve early diagnosis of diabetes patients. The system goals to increase the accuracy and efficacy of diabetes diagnosis by combining various machine learning algorithms and diverse datasets. This approach leads to proactive healthcare interventions and ultimately improves patient outcomes.

The Proposed Diabetes Prediction Empowered with Mutli-level Data Fusion and Machine Learning (DPEMDFML) model framework is presenting diabetes disease prediction. It

is carried out using the ANN and SVM algorithms, while using two different datasets.

The IoMT is necessary for enhancing the accuracy, reliability, and efficacy of electronic equipment in the medical field. By integrating the existing health care assets and medical facilities, experts are advancing a digital medical system [6]. The control of infectious disease waves is eased by prompt diagnosis and improved ongoing treatment. The internet of medical things (IoMT) is a growing area of technology that is now being used to assist Point-of-care testing (POCT). Using the IoMT, POCT devices may operate wirelessly and be connected to health professionals and medical facilities [7].

Recently has been discovered that developed ANNs may perform well in a variety of circumstances due to ANNs' universal prediction capabilities and adaptable network architectures [8]. The building block of the ANN created to mimic the function of a human neuron. Also, one of the greatest methods for analyzing data is the use of SVM. To control data, they utilize generalization controlling [9]. SVM is an artificial intelligence method that assigns labels to things by learning from examples [10]. The innovative and promising IoMT framework presented in this study represents a significant leap forward in the realm of diabetes disease prediction. Drawing upon the capabilities of two cutting-edge machine learning algorithms, ANN and SVM, this framework exemplifies the fusion of advanced technology and healthcare, offering a transformative approach to diabetes management and patient care. At its core, the IoMT framework capitalizes on the vast amount of data generated by interconnected medical devices, wearable sensors, and health monitoring systems. By harnessing this continuous and diverse stream of patient-specific information, healthcare providers gain unprecedented insights into the multifaceted aspects of diabetes, allowing for more precise, proactive, and personalized interventions. The first pillar of the framework, Artificial Neural Networks (ANN), represents a sophisticated computational model inspired by the complex interconnections of neurons in the human brain. ANN's ability to learn from data and recognize intricate patterns and non-linear relationships makes it an ideal candidate for diabetes prediction. The network's architecture is meticulously designed, leveraging multiple layers of interconnected neurons to extract high-level features from raw input data. The ANN's adaptability enables it to adjust its internal parameters during the learning process, optimizing the model's performance to achieve highly accurate diabetes predictions. In tandem with ANN, the IoMT framework also incorporates the renowned Support Vector Machine (SVM) algorithm, renowned for its prowess in binary classification tasks and its ability to handle complex decision boundaries. SVM's kernel-based approach allows it to efficiently discover non-linear patterns in the feature space, making it invaluable for diabetes prediction when the relationship between features and disease occurrence is intricate and not easily separable.

By integrating the capabilities of both ANN and SVM, the IoMT framework achieves a powerful ensemble of predictive models that complement each other's strengths. The diversity of these algorithms enhances the framework's ability to capture subtle nuances and intricate interactions within the data, ultimately leading to more reliable and accurate diabetes predictions. Data privacy and security are of paramount concern within the IoMT framework. Stringent measures are implemented to anonymize and safeguard patient information, and access controls are enforced to protect sensitive data from unauthorized disclosure. The framework's design ensures that data is utilized solely for model training purposes, mitigating the risk of data breaches and preserving patient confidentiality. The synergistic integration of ANNs and SVM algorithms within the IoMT framework marks a significant step towards personalized and data-driven diabetes prediction. With the potential to revolutionize healthcare practices, this cutting-edge approach empowers clinicians with actionable insights, fosters early detection, and facilitates effective diabetes management, ultimately enhancing the quality of life for patients worldwide.

The structure of the research paper is as follows: Section II represents the related work. In Section III, the contribution is presented. The detail of the proposed model is described in Section IV. Discussion and analysis of results are discussed in Section V. The conclusion of this research is presented in Section VI.

## II. RELATED WORK

The presented findings encompass various studies that examined different healthcare databases and utilized diverse approaches and strategies to make predictions. Researchers have developed and employed a range of prediction models, incorporating various data mining techniques, algorithmic methods for machine learning, or even a combination of these strategies. These studies highlight the wide array of approaches utilized in healthcare research to enhance prediction accuracy and improve decision-making processes.

Akkarapol and Jongsawas [11] presented a paper that analysed a dataset comprising 50,788 records with 43 parameters. The research identified significant risk variables, including age, BMI, overall revenue, sex, heart attack history, marital status, dentist check-up frequency, and diagnosis of asthma. Other risk factors such as hypertension and cholesterol were also recognized. The study's overall reliability was reported as 77.11%, indicating a moderate level of consistency in the findings. Furthermore, the true negative rate specifically for the Artificial Neural Network (ANN) model was noted as 79.45%, indicating its ability to accurately identify negative cases.

Kavakiotis et al.'s paper [12] focused on evaluating data mining and machine learning techniques for DM research. Through the systematic comparison of three algorithms, including Logistic Regression, Naive Bayes, and SVM, using 10-fold cross-validation, the study concluded that SVM achieved the highest accuracy rate of 84%. These findings contribute to the understanding of algorithm selection in DM research, highlighting the potential benefits of SVM in achieving accurate predictions and improving decision-making processes.

Xue-Hui Meng et al.'s study [13] focused on comparing the performance of decision tree models, ANNs, and logistic

regression in diagnosing diabetes or prediabetes based on general risk variables. The logistic regression model achieved a classification accuracy of 76.13%, indicating its ability to correctly classify individuals as having diabetes or prediabetes based on the general risk variables considered in the study. The decision tree model (C5.0) demonstrated a slightly higher classification accuracy of 77.87%. It also showed a relatively high sensitivity of 80.68%, meaning it successfully identified a large proportion of True Positive (TP) cases, and a specificity of 75.13%, indicating its capability to accurately identify True Negative (TN) cases. In contrast, the ANN model obtained a lower classification accuracy of 73.23%, suggesting that it was less effective in predicting the disease outcomes using the same set of general risk variables.

The research work conducted by Md. Faisal Faruque, Asaduzzaman, and Iqbal [14] focused on exploring the relationship between Diabetes Mellitus and multiple risk factors through the analysis of 16 attributes including factors such as age, diet, hypertension, vision problems, and genetic predisposition. By utilizing four popular machine learning algorithms, the researchers examined data from 200 patients. The findings of the study indicated that the Decision Tree algorithm demonstrated superior predictive performance compared to Support Vector Machine (SVM), Naive Bayes (NB), and K-Nearest Neighbour (KNN) algorithms in this particular study, suggesting its potential efficacy in predicting or classifying the disease based on the identified risk factors.

TABLE I.        LIMITATIONS OF THE PREVIOUS WORKS

| Research Study | Method | Accuracy | Limitation |
|---|---|---|---|
| Akkarapol and Jongsawas [11] | | 77.11% | - Low accuracy<br>- Limited to a specific region |
| Kavakiotis et al. [12] | | 84% | - Used three algorithms but the accuracy is low. |
| Xue-Hui Meng et al. [13] | Logistic Regression Model<br>Decision Tree Model (C5.0)<br>Artificial Neural Networks (ANN) Model | 76.13%<br>77.87%<br>73.23% | - Low accuracy<br>- Limited features of the dataset used |
| Md. Faisal Faruque, Asaduzzaman, and Iqbal [14] | Decision Tree Algorithm<br>Support Vector Machine (SVM)<br>Naive Bayes (NB)<br>K-Nearest Neighbour (KNN) | Not specified | - Small sample size<br>- Limited features |
| Dey et al. [15] | ANN Model with MMS | 82.35% | - Limited evaluation matrices |
| Pradhan et al. [16] | Ensemble Learning Approach | Not specified | - Multiple algorithms without mentioning accuracies |

The study conducted by Dey et al. [15] utilized four well-known supervised machine learning algorithms: SVM, KNN, Naive Bayes, and ANN with MMS. These algorithms were selected for their ability to learn from labelled data and make predictions based on learned patterns and relationships to analyse the Pima Indian dataset. The study revealed that the ANN model with MMS achieved the highest accuracy rate of 82.35%, indicating its potential effectiveness in predicting the specific outcome compared to the other four algorithms examined.

Pradhan et al. research [16] employed supervised learning, which involves training models on labelled data to make predictions, to develop models for diabetes diagnosis. Additionally, they utilized hybrid learning, which combines multiple learning techniques, to further enhance the performance of the diagnostic models. Finally, the researchers explored ensemble learning, a powerful approach that combines the predictions of multiple individual models, to create a more robust and accurate diabetes diagnosis model. The results of the study demonstrated that the ensemble learning approach surpassed both supervised learning and hybrid learning in terms of accuracy.

## III.    CONTRIBUTION

In contrast to previous research, this Diabetes Prediction Empowered with Multi-level Data Fusion and Machine Learning (DPEMDFML) model represents a more comprehensive study that explores various commonly used techniques for diabetes identification. The primary objective is to compare the performance of these techniques and identify the most effective one. It has been accomplished by employing two distinct algorithms and evaluating them on two different datasets, considering all relevant evaluation metrics. Furthermore, this study delves into analyzing the significance of each attribute in influencing the classification outcome. This analysis provides valuable insights for future research to adapt and improve the dataset, making it more informative and suitable for diabetes diagnosis tasks.

## IV.    PROPOSED MODEL

The Diabetes Prediction Empowered with Multi-level Data Fusion and Machine Learning (DPEMDFML) model developed here seeks to predict diabetes in a smart healthcare system utilizing data from the Internet of Medical Things (IoMT) is divided into two stages: training and testing as shown in Fig. 1. During the Training Phase, hospitals (Hospitals A, B, C, and N) use IoMT devices to gather patient data, which is subsequently recorded in their respective local databases. This information might include vital indicators, blood glucose levels, lifestyle information, and other information. The 'Prediction Layer,' which houses multiple ML models, with a focus on Support Vector Machines (SVM) and Artificial Neural Networks (ANN), is at the core of this phase.
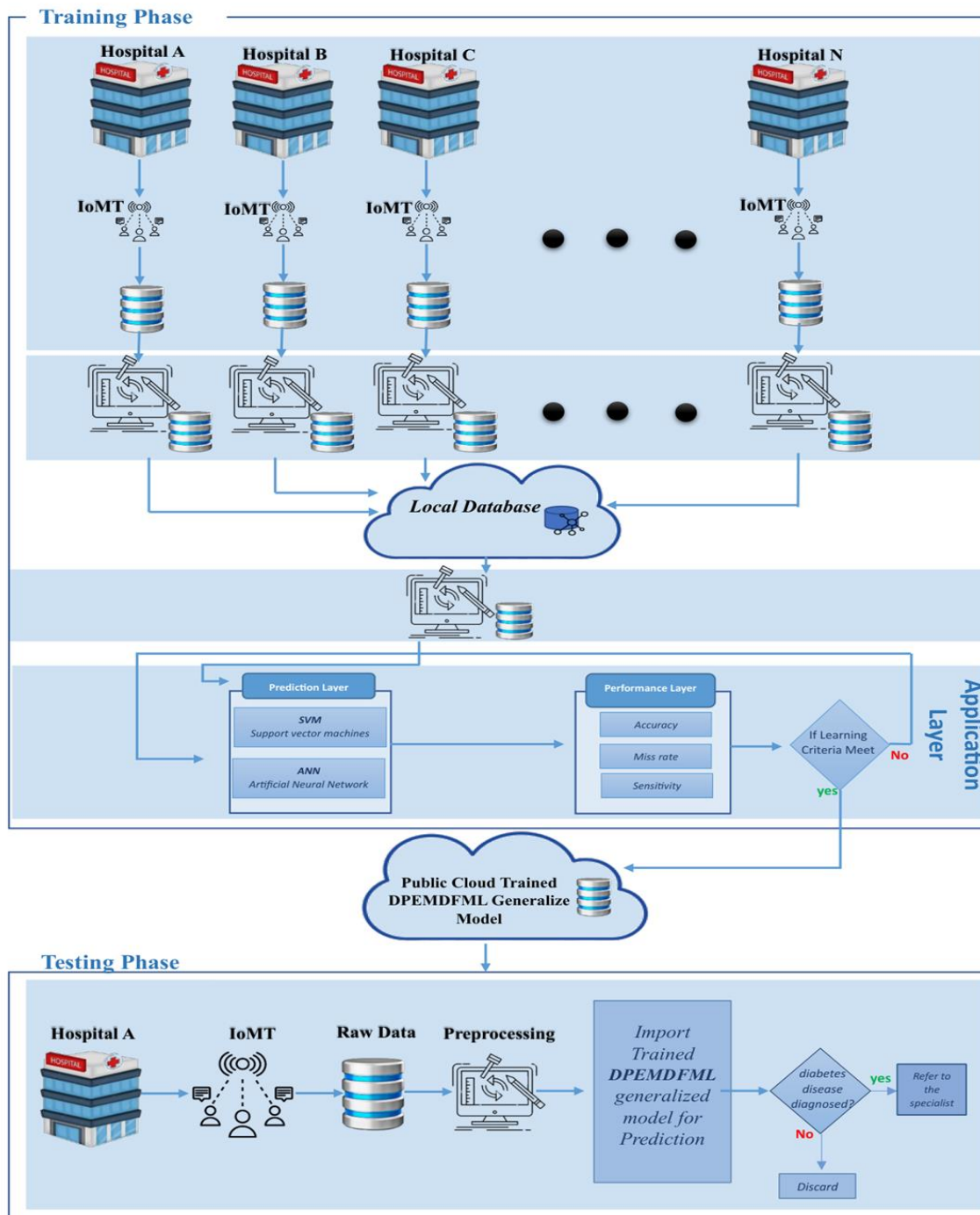
Fig. 1.   Diabetes prediction empowered with multi-level data fusion and machine learning (DPEMDFML).

These models excel at classification tasks and are in charge of learning whether a patient has diabetes depending on the input data. Following the Prediction Layer, Fig. 1 shows the Performance Layer assesses the efficiency of the ML models by employing measures such as accuracy, miss rate, and sensitivity. Models that match the performance criteria are saved in the public cloud as the "DPEMDFML Generalized Model", while those that fall short go through additional training rounds to enhance accuracy.

The trained DPEMDFML Generalized Model is used in the Testing Phase. When new patients from Hospital N seek diabetes diagnosis, the system gathers raw data from IoMT devices, which is then processed. Data cleansing, value normalization, and missing data management are examples of pre-processing operations that ensure the input data is ideal for the ML models' predictions.

The DPEMDFML Generalized Model is then used to predict whether or not the patient has diabetes. This decision-

making procedure has two results: If diabetes is predicted by the model, the patient is directed to a specialist for prompt medical intervention. If the model predicts a poor outcome, the data is properly deleted, protecting patient confidentiality and data privacy.

Because the system is distributed, various hospitals can contribute data, resulting in a broad and complete dataset for model training. Furthermore, the cloud-based architecture improves accessibility and scalability, allowing the system to meet growing data volumes as well as changing healthcare demands. The system benefits from the capabilities of SVM and ANN as its major ML models in pattern recognition, feature extraction, and classification, results in accurate diabetes predictions. Furthermore, the system's iterative training technique allows for continuous development, keeping the models current with medical advances.

The relevance of this ML-driven approach resides in its potential to improve diabetes diagnosis and patient treatment. The approach leverages the available information by utilizing data from IoMT devices across many hospitals, resulting in more reliable and exact predictions. The capacity to detect diabetic patients quickly and give early medical treatment assures improved disease control and perhaps improves patient outcomes. As the system evolves, its influence on the healthcare environment is expected to go beyond diabetes diagnosis, with the ability to tackle additional medical difficulties utilizing a similar distributed, ML-based approach.

The distributed, cloud-based machine learning system for diabetes detection using IoMT data is a potential improvement in healthcare technology. Its training and testing phases, which are supported by SVM and ANN models, show that it can handle complicated medical data and make correct predictions. As the system evolves via iterative training and embraces an ever-growing dataset, it is positioned to impact the future of medical diagnosis, eventually improving patient care and contributing to the healthcare industry's continuing transformation.

### A. Datasets

Diabetes Prediction Empowered with Mutli-level Data Fusion and Machine Learning (DPEMDFML) Model used two different datasets:

The primary dataset employed in this research is the PIMA Indian Diabetes Database, accessible at the University of California machine learning repository [14]. The dataset encompasses information from 768 individuals, all of whom are female, and their ages span from 21 to 81 years. For each individual, the dataset consists of nine distinct feature characteristics. These feature characteristics include eight continuous quantitative variables, namely the number of pregnancies, blood sugar level (in mg/dL), diastolic blood pressure (in mmHg), skin fold thickness (in mm), body mass index (BMI), serum insulin level (in mU/mL), age (in years), and a pedigree function associated with diabetes. By utilizing this comprehensive dataset, the study aims to explore the relationships between these feature characteristics and diabetes occurrence, enabling the development of predictive

models for early detection and assessment of diabetes risk in female patients.

For the second dataset used in this paper, it is called the "Diabetes prediction dataset," sourced from Electronic Health Records (EHRs) [15]. The dataset encompasses information from a substantial sample of 100,000 individuals, which were collected from diverse healthcare providers and then aggregated into a unified dataset. It is noteworthy that this dataset includes both female and male participants. The Diabetes prediction dataset consists of eight distinctive feature characteristics for each individual. These features include age, gender, hypertension, heart disease, smoking history, BMI (body mass index), HBA1C level (glycated haemoglobin level), and glucose level. By utilizing this comprehensive dataset, the study aims to explore the relationships between these feature characteristics and diabetes prediction. The inclusion of both genders and the diverse range of feature characteristics in this dataset facilitate a comprehensive analysis, providing valuable insights into predicting diabetes and its associated risk factors.

## V. RESULTS AND DISCUSSION

This section showcases the results of diabetes prediction using two different machine learning models: Support Vector Machine (SVM) and Artificial Neural Network (ANN). The prediction is conducted on two distinct datasets, and each dataset is split into two different ratios for training and testing: 70:30 and 75:25. Then, a range of evaluation metrics are calculated, include accuracy, miss-classification rate, sensitivity, specificity, precision, False positive (FP) rate, False discovery rate, False omission rate, Positive likelihood ratio,

Negative likelihood ratio, Prevalence threshold, critical success index, F1 Score, Mathews Correlation coefficient, Fowlkes-Mallows Index, informedness, and Diagnostic odds ratio. The following equations illustrate the equations used to calculate each of these metrics, providing a clear understanding of the underlying mathematical formulas for the statistical measurements [17-23]. The utilization of this diverse set of metrics ensures a comprehensive assessment of the models' performance, accounting for different aspects of predictive accuracy and error rates. Python is utilized as the simulation tool for implementing both the SVM model and ANN model, to obtain the results.

$$\text{Accuracy} = \frac{\text{Total Number of Predictions}}{\text{Number of Correct Predictions}} \quad (1)$$

$$\text{Miss classification rate } = 1 - \text{Accuracy} \quad (2)$$

$$Sensitivity = \frac{\text{True Positive}}{\text{True Positives+False Negatives}} \quad (3)$$

$$Specificity = \frac{\text{True Negatives}}{\text{True Negatives+False Positives}} \quad (4)$$

$$Precision = \frac{\text{True Positives}}{\text{True Positives+True Positives}} \quad (5)$$

$$False\ positive\ rate = \frac{\text{False Positives}}{\text{False Positives+True Negatives}} \quad (6)$$

$$False\ discovery\ rate = \frac{\text{False Positives}}{\text{False Positives+True Positives}} \quad (7)$$

$$False\ omission\ rate = \frac{False\ Negatives}{False\ Negatives + True\ Negatives} \quad (8)$$

$$Positive\ likelihood\ ration = \frac{Sensitivity}{1 - Specificity} \quad (9)$$

$$Negative\ likelihood\ ration = \frac{1 - Sensitivity}{Specificity} \quad (10)$$

$$Prevalence\ tholde = \sqrt{Sensitivity \times Specificity} \quad (11)$$

$$Critical\ sucess\ index = \frac{True\ Positives}{True\ Positives + False\ Negatives + False\ Positives} \quad (12)$$

$$F1\ score = \frac{2 \times Precision \times Sensitivity}{Precision + Sensitivity} \quad (13)$$

$$MCC = \frac{TP \times TN - FP \times FN}{\sqrt{(TP+FP)(TP+FN)(TN+FP)(TN+FN)}} \quad (14)$$

$$FMI = \sqrt{Sensitivity \times Precision} \quad (15)$$

$$Informedness = Sensitivity + Specificity - 1 \quad (16)$$

$$Diagnostic\ odds\ ratio = \frac{Positive\ likelihood\ ration}{Negative\ likelihood\ ration} \quad (17)$$

### A. DPEMDFML - SVM System Model - using Pima Diabetes Dataset - 70:30

Using SVM model with the Pima Diabetes Dataset, the dataset is divided as: 30% for testing (n=231) and 70% for training (n=537) to assess the model's performance accurately. The performance evaluation of the SVM model is depicted in Table II and Table III, which illustrate the confusion matrix. The confusion matrix provides crucial insights into the model's predictive accuracy, enabling a detailed examination of how well the SVM algorithm classifies diabetes and non-diabetes cases in the dataset.

During the training phase, the SVM model's predictions for diabetes disease are presented in Table II. The training dataset consists of 537 samples, which are further categorized into 187 real positive samples, indicating the presence of diabetes, and 350 real negative samples, indicating the absence of diabetes. Among the real positive samples (indicating the presence of diabetes), the SVM model correctly identifies 117 samples as positive, accurately signaling the presence of healthcare issues. However, the model misclassifies 70 records as negatives, incorrectly suggesting the absence of healthcare issues when there is an actual health concern. On the other hand, among the real negative samples (indicating the absence of diabetes), the SVM model correctly predicts 309 samples as negative, appropriately identifying the absence of healthcare conditions. However, the model makes errors in 41 samples, wrongly classifying them as positive, inaccurately indicating the presence of a healthcare issue when there is none.

During the testing phase, the SVM model's predictions for diabetes disease are presented in Table III. The testing dataset consists of 231 samples, which are further categorized into 81 real positive samples, indicating the presence of diabetes, and 150 real negative samples, indicating the absence of diabetes.

Among the real positive samples (indicating the presence of diabetes), the SVM model correctly identifies 48 samples as positive, accurately signaling the presence of healthcare issues. However, the model misclassifies 33 records as negatives, incorrectly suggesting the absence of healthcare issues when there is an actual health concern. However, the SVM model successfully predicted 124 samples as negative, properly recognizing the lack of medical diseases among the genuine negative samples (showing the absence of diabetes). But in 26 samples, the model misclassifies them as positive, thus implying the existence of a healthcare concern when there isn't one.

Table IV presents a comprehensive overview of the performance of the proposed SVM model in terms of various evaluation metrics. During the training phase, the SVM model achieved the following percentages for each metric: 79.32% accuracy, 20.67% miss-classification rate, 62.56% sensitivity, 88.28% specificity, 74.05% precision, 11.71% False positive rate, 25.94% False discovery rate, 18.46% False omission rate, 534.10% Positive likelihood ratio, 478.00% Negative likelihood ratio, 30.20% Prevalence threshold, 51.31% critical success index, 67.82% F1 Score, 53.16% Mathews Correlation coefficient, 68.06% Fowlkes-Mallows Index, 50.85% informedness, and 1259.68% Diagnostic odds ratio. During the validation phase, the performance of the model is evaluated, and the following evaluation metrics are obtained: 74.46% accuracy, 25.54% miss-classification rate, 59.25% sensitivity, 82.66% specificity, 64.86% precision, 17.33% False positive rate, 35.13% False discovery rate, 21.01% False omission rate, 341.88% Positive likelihood ratio, 393.29% Negative likelihood ratio, 35.10% Prevalence threshold, 44.86% critical success index, 61.93% F1 Score, 42.87% Mathews Correlation coefficient, 61.99% Fowlkes-Mallows Index, 41.92% informedness, and 693.70% Diagnostic odds ratio.

TABLE II.    SVM MODEL'S: PIMA DIABETES DATASET – TRAINING PHASE – 70:30

| Input | Total number of samples (537) | Result (output) | |
|---|---|---|---|
| | Expected output | Predicted positive | Predicted negative |
| | 187(positive) | 117(TP) | 70(FN) |
| | 350(negative) | 41(FP) | 309(TN) |

TABLE III.    SVM MODEL'S: PIMA DIABETES DATASET – TESTING PHASE – 70:30

| Input | Total number of samples (231) | Result (output) | |
|---|---|---|---|
| | Expected output | Predicted positive | Predicted negative |
| | 81(positive) | 48(TP) | 33(FN) |
| | 150(negative) | 26(FP) | 124(TN) |

TABLE IV. SVM MODEL'S (PIMA DIABETES DATASET) EVALUATION METRICS, 70:30

| | Testing | Training |
|---|---|---|
| Accuracy | 0.7445 (74.46 %) | 0.7932 (79.32 %) |
| Miss-classification rate | 0.2554 (25.54 %) | 0.2067 (20.67 %) |
| Sensitivity | 0.5925 (59.25 %) | 0.6256 (62.56 %) |
| Specificity | 0.8266 (82.66 %) | 0.8828 (88.28 %) |
| Precision | 0.6486 (64.86 %) | 0.7405 (74.05 %) |
| False positive rate | 0.1733 (17.33 %) | 0.1171 (11.71 %) |
| False discovery rate | 0.3513 (35.13 %) | 0.2594 (25.94%) |
| false omission rate | 0.2101 (21.01 %) | 0.1846 (18.46 %) |
| Positive likelihood ration | 3.4188 (341.88 %) | 5.3410 (534.10 %) |
| Negative likelihood ratio | 3.9329 (393.29 %) | 4.7800 (478.00 %) |
| prevalence threshold | 0.3510 (35.10 %) | 0.3020 (30.20 %) |
| critical success index | 0.4485 (44.859 %) | 0.5131 (51.31 %) |
| F1 Score | 0.6193 (61.93 %) | 0.6782 (67.82 %) |
| Mathews Correlation co-efficient | 0.4287 (42.87 %) | 0.5316 (53.16 %) |
| Fowlkes-Mallows Index | 0.6199 (61.99 %) | 0.6806 (68.06 %) |
| informedness | 0.4192 (41.92 %) | 0.5085 (50.85 %) |
| Diagnostic odds ratio | 6.9370 (693.70 %) | 12.5968 (1259.68 %) |

## B. *DPEMDFML - SVM System Model - using Pima Diabetes Dataset - 75:25*

Again, using SVM model with the Pima Diabetes Dataset. The dataset is divided into 25% for testing (n=192) and 75% for training (n=576) to assess the model's performance accurately. The performance evaluation of the SVM model is depicted in Table V and Table VI, which illustrate the confusion matrix.

Table V demonstrates the performance of the SVM model in predicting diabetic illness during the training phase. The training dataset comprises 576 samples, with 203 being true positive cases, indicating the presence of diabetes, and 373 being true negative cases, indicating the absence of diabetes. For the true positive cases, the SVM algorithm successfully identifies and correctly classifies 124 samples as positive, meaning that it accurately detects the absence of healthcare problems in those cases. However, the algorithm makes 79 errors by misclassifying some samples as negatives, falsely suggesting the absence of healthcare concerns when diabetes is actually present. Regarding the true negative cases, the SVM model performs well by accurately predicting and classifying 330 samples as negative, properly recognizing the absence of diabetes and the presence of other medical issues in those cases. Nevertheless, the model misclassifies 43 samples as positive, falsely indicating the presence of a healthcare issue when there is, in fact, no such health concern.

TABLE V. SVM MODEL'S - PIMA DIABETES DATASET – TRAINING PHASE – 75:25

| Input | Total number of samples (576) | Result (output) | |
|---|---|---|---|
| | Expected output | Predicted positive | Predicted negative |
| | *203(positive)* | *124(TP)* | *79(FN)* |
| | *373 (negative)* | *43(FP)* | *330(TN)* |

During the testing phase, Table VI showcases the SVM model's predictions for diabetes disease. The testing dataset consists of 192 samples, which are further categorized into 65 real positive samples, indicating the presence of diabetes, and 127 real negative samples, indicating the absence of diabetes. Among the real positive samples (indicating the presence of diabetes), the SVM model correctly identifies 36 samples as positive, accurately signaling the absence of healthcare issues. However, the model misclassifies 29 records as negatives, incorrectly suggesting the presence of healthcare issues when there is none. On the other hand, among the real negative samples (indicating the absence of diabetes), the SVM model correctly predicts 105 samples as negative, appropriately identifying the presence of healthcare conditions. However, the model makes errors in 22 samples, wrongly classifying them as positive, inaccurately indicating the absence of a healthcare issue when there is a health concern.

Table VII presents a comprehensive overview of the performance of the proposed SVM model in terms of various evaluation metrics. During the training phase, the SVM model achieved the following percentages for each metric: 78.81%, 21.18%, 61.08%, 88.47%, 74.25%, 11.52%, 25.74%, 19.31 %, 529.86 %, 458.03 %, 30.82%, 50.40%, 67.02%, 52.17%, 67.34%, 49.55%, 1204.59%, accuracy, miss-classification rate, sensitivity, specificity, precision, False positive rate, False discovery rate, False omission rate, Positive likelihood ratio, Negative likelihood ratio, Prevalence threshold, critical success index, F1 Score, Mathews Correlation coefficient, Fowlkes-Mallows Index, informedness, and Diagnostic odds ratio, respectively. During the validation phase, the performance of the model is evaluated, and the following evaluation metrics are obtained: 73.43% accuracy, 26.56 % miss-classification rate, 55. 38 % sensitivity, 82.67% specificity, 62.06% precision, 17.32% False positive rate, 37. 93% False discovery rate, 21.64% False omission rate, 319.72% Positive likelihood ratio, 382.02% Negative likelihood ratio, 35.86% Prevalence threshold, 41.37% critical success index, 58.53% F1 Score, 39.22% Mathews Correlation coefficient, 58.63% Fowlkes-Mallows Index, 38.06% informedness, and 592.47% Diagnostic odds ratio.

TABLE VI. SVM MODEL'S - PIMA DIABETES DATASET – TESTING PHASE – 75:25

| | Testing | Training |
|---|---|---|
| Accuracy | 0.7343 (73.43 %) | 0.7881 (78.81 %) |
| Miss-classification rate | 0.2656 (26.56 %) | 0.2118 (21.18 %) |
| Sensitivity | 0.5538 (55.38 %) | 0.6108 (61.08 %) |
| Specificity | 0.8267 (82.67 %) | 0.8847 (88.47 %) |
| Precision | 0.6206 (62.06 %) | 0.7425 (74.25 %) |
| False positive rate | 0.1732 (17.32 %) | 0.1152 (11.52 %) |
| False discovery rate | 0.3793 (37. 93 %) | 0.2574 (25.74%) |
| false omission rate | 0.2164 (21.64%) | 0.1931 (19.31 %) |
| Positive likelihood ration | 3.1972 (319.72 %) | 5.2986 (529.86 %) |
| Negative likelihood ratio | 3.8202 (382.02 %) | 4.5803 (458.03 %) |
| prevalence threshold | 0.3586 (35.86 %) | 0.3028 (30.82 %) |
| critical success index | 0.4137 (41.37 %) | 0.5040 (50.40 %) |

| F1 Score | 0.5853<br>(58.53 %) | 0.6702<br>(67.02 %) |
| Mathews Correlation co-efficient | 0.3922<br>(39.22 %) | 0.5217<br>(52.17 %) |
| Fowlkes-Mallows Index | 0.5863<br>(58.63 %) | 0.6734<br>(67.34 %) |
| informedness | 0.3806<br>(38.06 %) | 0.4955<br>(49.55 %) |
| Diagnostic odds ratio | 5.9247<br>(592.47 %) | 12.0459<br>(1204.59 %) |

TABLE VII.   SVM Model's (Pima Diabetes Dataset) Evaluation Metrics, 75:25

|  | Testing | Training |
|---|---|---|
| Accuracy | 0.7343<br>(73.43 %) | 0.7881<br>(78.81 %) |
| Miss-classification rate | 0.2656<br>(26.56 %) | 0.2118<br>(21.18 %) |
| Sensitivity | 0.5538<br>(55.38 %) | 0.6108<br>(61.08 %) |
| Specificity | 0.8267<br>(82.67 %) | 0.8847<br>(88.47 %) |
| Precision | 0.6206<br>(62.06 %) | 0.7425<br>(74.25 %) |
| False positive rate | 0.1732<br>(17.32 %) | 0.1152<br>(11.52 %) |
| False discovery rate | 0.3793<br>(37. 93 %) | 0.2574<br>(25.74%) |
| false omission rate | 0.2164<br>(21.64%) | 0.1931<br>(19.31 %) |
| Positive likelihood ration | 3.1972<br>(319.72 %) | 5.2986<br>(529.86 %) |
| Negative likelihood ratio | 3.8202<br>(382.02 %) | 4.5803<br>(458.03 %) |
| prevalence threshold | 0.3586<br>(35.86 %) | 0.3028<br>(30.82 %) |
| critical success index | 0.4137<br>(41.37 %) | 0.5040<br>(50.40 %) |
| F1 Score | 0.5853<br>(58.53 %) | 0.6702<br>(67.02 %) |
| Mathews Correlation co-efficient | 0.3922<br>(39.22 %) | 0.5217<br>(52.17 %) |
| Fowlkes-Mallows Index | 0.5863<br>(58.63 %) | 0.6734<br>(67.34 %) |
| informedness | 0.3806<br>(38.06 %) | 0.4955<br>(49.55 %) |
| Diagnostic odds ratio | 5.9247<br>(592.47 %) | 12.0459<br>(1204.59 %) |

## C. DPEMDFML - SVM System Model - using EHRs Dataset - 70:30

The SVM model was utilized in this study with the EHRs Dataset (Electronic Health Records Dataset). To ensure a robust evaluation of the model's performance, the dataset was divided into 30% for testing (n=30,000) and 70% for training (n=70,000). To assess the effectiveness of the SVM model, its performance was analysed using two distinct evaluation tables: Table VIII and Table IX, both presenting the confusion matrix.

During the training phase, the SVM model's diabetes predictions are presented in Table VIII. The training dataset consists of an extensive sample of 70,000 records, which are further categorized into 5,972 instances as positive cases, indicating the presence of diabetes, and 64,028 instances as negative cases, indicating the absence of diabetes. Among the actual positive cases, the SVM model correctly identifies 3,621 samples as positive, correctly indicating the absence of healthcare issues. However, the model misclassifies 2,351 records as negative, falsely signalling the presence of healthcare issues where there are none. On the other hand, among the actual negative cases, the SVM model accurately predicts 63,602 samples as negative, correctly identifying the presence of healthcare conditions. However, the model makes errors in 426 samples, incorrectly classifying them as positive, falsely indicating the absence of a healthcare issue.

During the testing phase, the SVM model's predictions for diabetes disease are displayed in Table IX. The testing dataset comprises 30,000 samples, which are further categorized into 2,528 true positive cases, indicating the presence of diabetes, and 27,472 true negative cases, indicating the absence of diabetes. Among the true positive cases, the SVM model correctly classifies 1,515 samples as positive, accurately indicating the absence of any healthcare issues. However, the model misclassifies 1,013 records as negative, falsely indicating the presence of healthcare issues when there are none. Conversely, among the true negative cases, the SVM model accurately predicts 27,298 samples as negative, correctly identifying the presence of healthcare conditions. Nevertheless, the model makes errors in 174 samples, incorrectly classifying them as positive, falsely indicating the absence of a healthcare issue.

Table X presents a comprehensive overview of the performance of the proposed SVM model in terms of various evaluation metrics. During the training phase, the SVM model achieved the following percentages for each metric: 96.03%, 3.96%, 60.63%, 99.33%, 89.47%, 0.66%, 10.52%, 3.56%, 9113.16%, 2786.65%, 9.48%, 56.59%, 72.28%, 71.77%, 73.65%, 59.96%, 22995.19%, accuracy, miss-classification rate, sensitivity, specificity, precision, False positive rate, False discovery rate, False omission rate, Positive likelihood ratio, Negative likelihood ratio, Prevalence threshold, critical success index, F1 Score, Mathews Correlation coefficient, Fowlkes-Mallows Index, informedness, and Diagnostic odds ratio, respectively. During the validation phase, the performance of the model is evaluated, and the following evaluation metrics are obtained: 96.04%, 3.95%, 59.92%, 99.36%, 89.69%, 0.63%, 10.3%, 3.57%, 9461.86%, 2777.06%, 9.32%, 56.06%, 71.85%, 71.45%, 73.31%, 59.29%, 23463.06%, accuracy, miss-classification rate, sensitivity, specificity, precision, False positive rate, False discovery rate, False omission rate, Positive likelihood ratio, Negative likelihood ratio, Prevalence threshold, critical success index, F1 Score, Mathews Correlation coefficient, Fowlkes-Mallows Index, informedness, and Diagnostic odds ratio, respectively.

## D. DPEMDFML - SVM System Model - using EHRs Dataset – 75:25

Here, the SVM model with the EHRs Dataset (Electronic Health Records Dataset) is employed. To ensure a robust assessment of the model's performance, the dataset was split into 25% for testing (n=25,000) and 75% for training (n=75,000). To evaluate the SVM model's effectiveness, two different evaluation tables was used to analyse its performance: Table XI and Table XII, which present the confusion matrix.

During the training phase, the SVM model's diabetes predictions are presented in Table XI. The training dataset consists of 75,000 samples, which are further categorized into 6,409 true positive cases, indicating the presence of diabetes, and 68,591 true negative cases, indicating the absence of diabetes. Among the true positive cases, the SVM model correctly identifies 3,876 samples as positive, accurately indicating the absence of healthcare issues. However, the model misclassifies 2,533 records as negative, falsely signalling the presence of healthcare issues where there are none. On the other hand, among the true negative cases, the SVM model accurately predicts 68,111 samples as negative, correctly identifying the presence of healthcare conditions. However, the model makes errors in 480 samples, incorrectly classifying them as positive, falsely indicating the absence of a healthcare issue.

TABLE VIII.    SVM MODEL'S - EHRS DIABETES DATASET – TRAINING PHASE – 70:30

| Input | Total number of samples (70000) | Result (output) | |
|---|---|---|---|
| | Expected output | Predicted positive | Predicted negative |
| | 5972(positive) | 3621(TP) | 2351(FN) |
| | 64028(negative) | 426(FP) | 63602(TN) |

TABLE IX.    SVM MODEL'S - EHRS DIABETES DATASET – TESTING PHASE – 70:30

| Input | Total number of samples (30000) | Result (output) | |
|---|---|---|---|
| | Expected output | Predicted positive | Predicted negative |
| | 2528(positive) | 1515(TP) | 1013(FN) |
| | 27472(negative) | 174(FP) | 27298(TN) |

TABLE X.    SVM MODEL'S (EHRs DIABETES DATASET) EVALUATION METRICS, 70:30

|  | Testing | Training |
|---|---|---|
| Accuracy | 0.9604 (96.04 %) | 0.9603 (96.03 %) |
| Miss-classification rate | 0.0395 (3. 95 %) | 0.0396 (3.96 %) |
| Sensitivity | 0.5992 (59.92 %) | 0.6063 (60.63 %) |
| Specificity | 0.9936 (99.36 %) | 0.9933 (99.33 %) |
| Precision | 0.8969 (89.69 %) | 0.8947 (89.47 %) |
| False positive rate | 0.0063 (0.63 %) | 0.0066 (0.66 %) |
| False discovery rate | 0.1030 (10. 3 %) | 0.1052 (10.52%) |
| false omission rate | 0.0357 (3.57 %) | 0.0356 (3.56 %) |
| Positive likelihood ration | 94.6186 (9461.86 %) | 91.1316 (9113.16 %) |
| Negative likelihood ratio | 27.7706 (2777.06 %) | 27.8665 (2786.65 %) |
| prevalence threshold | 0.0932 (9.32%) | 0.0948 (9.48 %) |
| critical success index | 0.5606 (56.06 %) | 0.5659 (56.59 %) |
| F1 Score | 0.7185 (71.85 %) | 0.7228 (72.28 %) |
| Mathews Correlation co-efficient | 0.7145 (71.45 %) | 0.7177 (71.77 %) |
| Fowlkes-Mallows Index | 0.7331 (73.31 %) | 0.7365 (73.65 %) |
| informedness | 0.5929 (59.29 %) | 0.5996 (59.96 %) |
| Diagnostic odds ratio | 234.6306 (23463.06 %) | 229.9519 (22995.19 %) |

During the testing stage, Table XII showcases the SVM model's diabetes predictions. The test dataset comprises 25,000 samples, split into 2,091 true positive cases (indicating the presence of diabetes) and 22,909 true negative cases (indicating the absence of diabetes). Among the true positive cases, the SVM model accurately identifies 1,266 samples as positive, correctly indicating the absence of healthcare issues. However, the model misclassifies 825 records as negative, erroneously suggesting the presence of healthcare issues. Conversely, among the true negative cases, the SVM model precisely predicts 22,758 samples as negative, correctly recognizing the presence of healthcare conditions. However, the model makes 151 errors, incorrectly classifying them as positive, falsely indicating the absence of healthcare issues.

Table XIII presents a comprehensive overview of the performance of the proposed SVM model in terms of various evaluation metrics. During the training phase, the SVM model achieved the following percentages for each metric: 95.98%, 4.01%, 60.47%, 99.30%, 88.98%, 0.69%, 11.01%, 3.58%, 8642.10%, 2769.42%, 9.71%, 56.26%, 72.01%, 71.44%, 73.35%, 59.77%, 21713.23%, accuracy, miss-classification rate, sensitivity, specificity, precision, False positive rate, False discovery rate, False omission rate, Positive likelihood ratio, Negative likelihood ratio, Prevalence threshold, critical success index, F1 Score, Mathews Correlation coefficient, Fowlkes-Mallows Index, informedness, and Diagnostic odds ratio, respectively. During the validation phase, the performance of the model is evaluated, and the following evaluation metrics are obtained: 96.09%, 3.90%, 60.54%, 99.34%, 89.34%, 0.65%, 10.65%, 3.49%, 9185.62%, 2839.70%, 9.44%, 56.46%, 72.17%, 71.70%, 73.54%, 59.88%, 23127.93%, accuracy, miss-classification rate, sensitivity, specificity, precision, False positive rate, False discovery rate, False omission rate, Positive likelihood ratio, Negative likelihood ratio, Prevalence threshold, critical success index, F1 Score, Mathews Correlation coefficient, Fowlkes-Mallows Index, informedness, and Diagnostic odds ratio, respectively.

TABLE XI.    SVM MODEL'S - EHRs DIABETES DATASET – TRAINING PHASE – 75:25

| Input | Total number of samples (75000) | Result (output) | |
|---|---|---|---|
| | Expected output | Predicted positive | Predicted negative |
| | 6409(positive) | 3876(TP) | 2533(FN) |
| | 68591(negative) | 480(FP) | 68111(TN) |

TABLE XII.    SVM MODEL'S - EHRS DIABETES DATASET – TESTING PHASE – 75:25

| | Total number of samples (25000) | | Result (output) | |
|---|---|---|---|---|
| | Expected output | | Predicted positive | Predicted negative |
| Input | 2091(positive) | | 1266(TP) | 825(FN) |
| | 22909(negative) | | 151(FP) | 22758(TN) |

TABLE XIII.   SVM MODEL'S (EHRS DIABETES DATASET) EVALUATION METRICS, 75:25

| | Testing | Training |
|---|---|---|
| Accuracy | 0.9609 (96.09 %) | 0.9598 (95.98 %) |
| Miss-classification rate | 0.0390 (3.90 %) | 0.0401 (4.01 %) |
| Sensitivity | 0.6054 (60.54 %) | 0.6047 (60.47 %) |
| Specificity | 0.9934 (99.34 %) | 0.9930 (99.30 %) |
| Precision | 0.8934 (89.34 %) | 0.8898 (88.98 %) |
| False positive rate | 0.0065 (0.65 %) | 0.0069 (0.69 %) |
| False discovery rate | 0.1065 (10. 65 %) | 0.1101 (11.01%) |
| false omission rate | 0.0349 (3.49%) | 0.0358 (3.58 %) |
| Positive likelihood ration | 91.8562 (9185.62 %) | 86.4210 (8642.10 %) |
| Negative likelihood ratio | 28.3970 (2839.70 %) | 27.6942 (2769.42 %) |
| prevalence threshold | 0.0944 (9.44 %) | 0.0971 (9.71 %) |
| critical success index | 0.5646 (56.46 %) | 0.5626 (56.26 %) |
| F1 Score | 0.7217 (72.17 %) | 0.7201 (72.01 %) |
| Mathews Correlation co-efficient | 0.7170 (71.70 %) | 0.7144 (71.44 %) |
| Fowlkes-Mallows Index | 0.7354 (73.54 %) | 0.7335 (73.35 %) |
| informedness | 0.5988 (59.88 %) | 0.5977 (59.77 %) |
| Diagnostic odds ratio | 231.2793 (23127.93 %) | 217.1323 (21713.23 %) |

## E. DPEMDFML - ANN System Model - using Pima Diabetes Dataset - 70:30

Shifting our focus to the second algorithm used in this research, the Artificial Neural Network (ANN) model was employed, and the Pima Diabetes Dataset was utilized for evaluation. To ensure a robust assessment of the model's effectiveness, the dataset was split into two sets: 20% for testing (n=231) and 70% for training (n=537). To gauge the performance of the ANN model, a detailed analysis was conducted using two distinct evaluation tables: Table XIV and Table XV. These tables present the confusion matrix, providing valuable insights into the model's ability to deliver accurate predictions during both the testing and training phases.

During the training stage, Table XIV illustrates the ANN model's predictions for diabetes disease. The training dataset consists of 537 samples, further divided into 188 true positive cases, indicating the presence of diabetes, and 349 true negative cases, indicating the absence of diabetes. Among the true positive cases, the ANN model correctly identifies 157 samples as positive, accurately indicating the absence of healthcare issues. However, the model misclassifies 31 records as negative, falsely indicating the presence of healthcare issues. Conversely, among the true negative cases, the ANN model accurately predicts 327 samples as negative, correctly identifying the presence of healthcare conditions. However, the model makes 22 errors, incorrectly classifying them as positive, falsely indicating the absence of a healthcare issue.

During the testing phase, the ANN model's predictions for diabetes disease are shown in Table XV. The testing dataset consists of 231 samples, further divided into 80 true positive cases, indicating the presence of diabetes, and 151 true negative cases, indicating the absence of diabetes. Among the

true positive cases, the ANN model correctly identifies 47 samples as positive, accurately indicating the absence of healthcare issues. However, the model misclassifies 33 records as negative, falsely signalling the presence of healthcare issues where there are none. On the other hand, among the true negative cases, the ANN model accurately predicts 116 samples as negative, correctly identifying the presence of healthcare conditions. However, the model makes 35 errors, incorrectly classifying them as positive, falsely indicating the absence of a healthcare issue.

Table XVI provides a comprehensive summary of the proposed ANN model's performance during the training phase, showcasing various evaluation metrics. The percentages for each metric achieved by the ANN model are as follows: 90.13% accuracy, 9.86% miss-classification rate, 83.51% sensitivity, 93.69% specificity, 87.70% precision, 6.30% false positive rate, 12.29% false discovery rate, 6.30% false omission rate, 1324.78% positive likelihood ratio, 17.59% negative likelihood ratio, 44.90% prevalence threshold, 77.20% critical success index, 85.55% F1 Score, 78.12% Mathews Correlation coefficient, 83.78% Fowlkes-Mallows Index, 77.20% informedness, and 7527.71% diagnostic odds ratio. During the validation phase, the performance of the model is evaluated, and the following evaluation metrics are obtained: 70.56%, 29.43%, 58.75%,

76.82%, 57.31%, 23.17%, 42.68%, 23.17%, 253.46%, 53.69%, 40.96%, 35.57%, 58.02%, 35.36%, 61.55%, 35.57%, 472.03%, accuracy, miss-classification rate, sensitivity, specificity, precision, False positive rate, False discovery rate, False omission rate, Positive likelihood ratio, Negative likelihood ratio, Prevalence threshold, critical success index, F1 Score, Mathews Correlation coefficient, Fowlkes-Mallows Index, informedness, and Diagnostic odds ratio, respectively.

TABLE XIV. ANN MODEL'S - PIMA DIABETES DATASET – TRAINING PHASE – 70:30

| | Total number of samples (537) | Result (output) | |
|---|---|---|---|
| Input | *Expected output* | *Predicted positive* | *Predicted negative* |
| | *188(positive)* | *157(TP)* | *31(FN)* |
| | *349 (negative)* | *22(FP)* | *327 (TN)* |

TABLE XV. ANN MODEL'S - PIMA DIABETES DATASET – TESTING PHASE – 70:30

| | Total number of samples (231) | Result (output) | |
|---|---|---|---|
| Input | Expected output | Predicted positive | Predicted negative |
| | 80(positive) | 47(TP) | 33(FN) |
| | 151(negative) | 35(FP) | 116(TN) |

TABLE XVI. ANN MODEL'S (PIMA DIABETES DATASET) EVALUATION METRICS, 70:30

| | Testing | Training |
|---|---|---|
| Accuracy | 0.7056 (70.56 %) | 0.9013 (90.13%) |
| Miss-classification rate | 0.2943 (29.43 %) | 0.0986 (9.86 %) |
| Sensitivity | 0.5875 (58.75 %) | 0.8351 (83.51%) |
| Specificity | 0.7682 (76.82 %) | 0.9369 (93.69 %) |
| Precision | 0.5731 (57.31 %) | 0.8770 (87.70%) |
| False positive rate | 0.2317 (23.17 %) | 0.0630 (6.30 %) |
| False discovery rate | 0.4268 (42. 68 %) | 0.1229 (12.29 %) |
| false omission rate | 0.2317 (23.17%) | 0.06303 (6.30 %) |
| Positive likelihood ration | 2.5346 (253.46 %) | 13.2478 (1324.78 %) |
| Negative likelihood ratio | 0.5369 (53.69 %) | 0.1759 (17.59 %) |
| prevalence threshold | 0.4096 (40.96 %) | 0.4490 (44.90 %) |
| critical success index | 0.3557 (35.57 %) | 0.7720 (77.20 %) |
| F1 Score | 0.5802 (58.02 %) | 0.8555 (85.55 %) |
| Mathews Correlation co-efficient | 0.3536 (35.36 %) | 0.7812 (78.12 %) |
| Fowlkes-Mallows Index | 0.6155 (61.55 %) | 0.8378 (83.78 %) |
| Informedness | 0.3557 (35.57 %) | 0.7720 (77.20 %) |
| Diagnostic odds ratio | 4.7203 (472.03 %) | 75.2771 (7527.71 %) |

### F. DPEMDFML - ANN System Model - using Pima Diabetes Dataset - 75:25

Once more, the ANN model was utilized with the Pima Diabetes Dataset. The dataset here was split into 25% for testing (n=192) and 75% for training (n=576) to ensure a thorough evaluation of the model's performance. The performance metrics of the ANN model are presented in Table XVII and Table XVIII, displaying the confusion matrix results.

During the training phase, Table XVII showcases the ANN model's predictions for diabetes disease. Out of the 576 samples used for training, 199 are identified as real positive cases, and 377 as real negative cases. Among these, 172 are correctly identified as positive, meaning no healthcare issues have been observed, while 27 are incorrectly projected as negatives, indicating a healthcare issue is present. Regarding the 377 samples with negative results, indicating the presence of a healthcare condition, 352 samples are correctly forecasted as negative, and 25 samples are wrongly forecasted as positive, indicating the absence of a healthcare issue.

During the testing phase, Table XVIII displays the ANN model's predictions for diabetes disease. The dataset consists of 192 samples, divided into 69 real positive cases and 123 real negative cases. Among these, the model correctly identifies 45 samples as positive, indicating no healthcare issues observed, while 24 samples are incorrectly projected as negatives, suggesting a healthcare issue. For the 123 samples with negative results, indicating the presence of a healthcare condition, the model appropriately forecasts 92 as negative, and 31 samples are wrongly forecasted as positive, indicating the absence of a healthcare issue.

Table XIX provides a comprehensive summary of the proposed ANN model's performance during the training phase, showcasing various evaluation metrics. The percentages for each metric achieved by the ANN model are as follows: 90.97%, 9.02%, 86.43%, 93.36%, 87.30%, 6.63%, 12.96%, 5.88%, 1303.39%, 14.53%, 46.53%, 79.80%, 86.86%, 79.99%, 84.98%, 79.80%, 8969.48%, accuracy, miss-classification rate, sensitivity, specificity, precision, False positive rate, False discovery rate, False omission rate, Positive likelihood ratio, Negative likelihood ratio, Prevalence threshold, critical success index, F1 Score, Mathews Correlation coefficient, Fowlkes-Mallows Index, informedness, and Diagnostic odds ratio, respectively. During the validation phase, the performance of the model is evaluated, and the following evaluation metrics are obtained: 71.35%, 28.64%, 65.21%, 74.79%, 59.21%, 25.20%, 40.78%, 20.68%, 258.76%, 46.50%, 45.21%, 40.01%, 62.06%, 39.26%, 61.10%, 40.01%, 556.45%, accuracy, miss-classification rate, sensitivity, specificity, precision, False positive rate, False discovery rate, False omission rate, Positive likelihood ratio, Negative likelihood ratio, Prevalence threshold, critical success index, F1 Score, Mathews

Correlation coefficient, Fowlkes-Mallows Index, informedness, and Diagnostic odds ratio, respectively.

### G. DPEMDFML - ANN System Model - using EHRs Dataset - 70:30

Utilizing the same algorithm, the ANN model applied to the second dataset, referred to as the EHRs Dataset (Electronic Health Records Dataset). To achieve a comprehensive evaluation of the model's performance, the data set was split as: 30% for testing (n = 30,000) and 70% for training (n = 70,000). The effectiveness of the ANN model was assessed through a thorough analysis of its performance using two separate evaluation tables: Table XX and Table XXI. These tables present detailed information from the confusion matrix, offering insights into the model's performance during both the testing and training phases.

During the training phase, Table XX displays the outcomes of the ANN model's predictions for diabetes disease. In this phase, the model uses a dataset consisting of 70,000 samples, which are further divided into 5,972 real positive cases and 64,028 real negative cases. Among the real positive cases, 4,265 samples are correctly identified as positive, indicating the absence of healthcare issues. However, 1,707 samples are incorrectly classified as negatives, implying potential healthcare concerns. Regarding the real negative cases, which represent the presence of a healthcare condition, the model accurately predicts 63,938 samples as negative, indicating the presence of healthcare issues. However, 90 samples are falsely predicted as positive, suggesting the absence of healthcare issues, when in fact, they should have been classified as negative.

TABLE XVII.  ANN MODEL'S - PIMA DIABETES DATASET – TRAINING PHASE – 75:25

| Input | Total number of samples (576) | Result (output) | |
|---|---|---|---|
| | Expected output | Predicted positive | Predicted negative |
| | 199(positive) | 172(TP) | 27(FN) |
| | 377 (negative) | 25(FP) | 352(TN) |

TABLE XVIII. ANN MODEL'S - PIMA DIABETES DATASET – TESTING PHASE – 75:25

| Input | Total number of samples (192) | Result (output) | |
|---|---|---|---|
| | Expected output | Predicted positive | Predicted negative |
| | 69(positive) | 45(TP) | 24(FN) |
| | 123(negative) | 31(FP) | 92(TN) |

TABLE XIX.   ANN MODEL'S (PIMA DIABETES DATASET) EVALUATION METRICS, 75:25

| | Testing | Training |
|---|---|---|
| Accuracy | 0.7135 (71.35 %) | 0.9097 (90.97%) |
| Miss-classification rate | 0.2864 (28.64 %) | 0.0902 (9.02 %) |
| Sensitivity | 0.6521 (65.21 %) | 0.8643 (86.43%) |
| Specificity | 0.7479 (74.79 %) | 0.9336 (93.36 %) |
| Precision | 0.5921 (59.21 %) | 0.8730 (87.30%) |
| False positive rate | 0.2520 (25.20 %) | 0.0663 (6.63 %) |
| False discovery rate | 0.4078 (40.78 %) | 0.1269 (12.96 %) |
| false omission rate | 0.2068 (20.68 %) | 0.0588 (5.88 %) |
| Positive likelihood ration | 2.5876 (258.76 %) | 13.0339 (1303.39 %) |
| Negative likelihood ratio | 0.4650 (46.50 %) | 0.1453 (14.53 %) |
| prevalence threshold | 0.4521 (45.21 %) | 0.4653 (46.53 %) |
| critical success index | 0.4001 (40.01 %) | 0.7980 (79.80 %) |
| F1 Score | 0.6206 (62.06 %) | 0.8686 (86.86 %) |
| Mathews Correlation co-efficient | 0.3926 (39.26 %) | 0.7999 (79.99 %) |
| Fowlkes-Mallows Index | 0.6110 (61.10 %) | 0.8498 (84.98 %) |
| informedness | 0.4001 (40.01 %) | 0.7980 (79.80 %) |
| Diagnostic odds ratio | 5.5645 (556.45 %) | 89.6948 (8969.48 %) |

During the testing phase, Table XXI demonstrates the ANN model's performance in predicting diabetes disease. The dataset used for testing consists of 30,000 samples, which are further divided into 2,528 actual positive cases and 27,472 actual negative cases. The model correctly identifies 1,754 positive cases, indicating the absence of healthcare issues. However, it mistakenly classifies 774 positive cases as negative, suggesting possible healthcare concerns. For the actual negative cases, which indicate the presence of healthcare conditions, the model accurately predicts 27,368 samples as negative. This demonstrates its ability to identify the presence of healthcare issues correctly. Nevertheless, there are 104 false positive predictions, where the model incorrectly identifies cases as negative, indicating the absence of healthcare issues when they should have been classified as positive.

Table XXII provides a comprehensive summary of the proposed ANN model's performance during the training phase, showcasing various evaluation metrics. The percentages for each metric achieved by the ANN model are as follows: 97.43% accuracy, 2.56% miss-classification rate, 71.41% sensitivity, 99.85% specificity, 97.93% precision, 0.14% false positive rate, 2.06% false discovery rate, 2.60% false omission rate, 50807.36% positive likelihood ratio, 28.62% negative likelihood ratio, 35.77% prevalence threshold, 71.27% critical success index, 82.59% F1 Score, 82.43% Mathews Correlation coefficient, 97.12% Fowlkes-Mallows Index, and 177501.51% diagnostic odds ratio. During the validation phase, the performance of the model is evaluated, and the following evaluation metrics are obtained: 97.07% accuracy, 2.92% miss-classification rate, 69.38% sensitivity, 99.62% specificity, 94.40% precision, 0.37% false positive rate, 5.59% false discovery rate, 2.75 % false omission rate, 18327.76% positive likelihood ratio, 30.733% negative likelihood ratio, 34.88% prevalence threshold, 69.00% critical success index, 79.98% F1 Score, 79.52% Mathews Correlation coefficient, 96.73% Fowlkes-Mallows Index, and 59634.60% diagnostic odds ratio.

TABLE XX.   ANN MODEL'S - EHRS DIABETES DATASET – TRAINING PHASE – 70:30

| Input | Total number of samples (70000) | Result (output) | |
|---|---|---|---|
| | Expected output | Predicted positive | Predicted negative |
| | 5972(positive) | 4265 (TP) | 1707 (FN) |
| | 64028 (negative) | 90 (FP) | 63938(TN) |

TABLE XXI.   ANN MODEL'S - EHRs DIABETES DATASET – TESTING PHASE – 70:30

| Input | Total number of samples (30000) | Result (output) | |
|---|---|---|---|
| | Expected output | Predicted positive | Predicted negative |
| | 2528(positive) | 1754 (TP) | 774 (FN) |
| | 27472(negative) | 104 (FP) | 27368 (TN) |

TABLE XXII.  ANN MODEL'S (EHRs DIABETES DATASET) EVALUATION METRICS, 70:30

| | Testing | Training |
|---|---|---|
| Accuracy | 0.9707 (97.07 %) | 0.9743 (97.43 %) |
| Miss-classification rate | 0.0292 (2.92 %) | 0.0256 (2.56 %) |
| Sensitivity | 0.6938 (69.38 %) | 0.7141 (71.41 %) |
| Specificity | 0.9962 (99.62 %) | 0.9985 (99.85 %) |
| Precision | 0.9440 (94.40 %) | 0.9793 (97.93 %) |
| False positive rate | 0.0037 (0.37 %) | 0.0014 (0.14 %) |
| False discovery rate | 0.0559 (5.59 %) | 0.0206 (2.06 %) |
| false omission rate | 0.0275 (2.75 %) | 0.0260 (2.60 %) |
| Positive likelihood ration | 183.2776 (18327.76 %) | 508.0736 (50807.36 %) |
| Negative likelihood ratio | 0.30733 (30.733 %) | 0.2862 (28.62 %) |
| prevalence threshold | 0.3488 (34.88 %) | 0.3577 (35.77 %) |
| critical success index | 0.6900 (69.00 %) | 0.7127 (71.27 %) |
| F1 Score | 0.7998 (79.98 %) | 0.8259 (82.59 %) |
| Mathews Correlation co-efficient | 0.7952 (79.52 %) | 0.8243 (82.43 %) |
| Fowlkes-Mallows Index | 0.9673 (96.73 %) | 0.9712 97.12 %) |
| Informedness | 0.6900 (69.00 %) | 0.7127 (71.27 %) |
| Diagnostic odds ratio | 596.3460 (59634.60 %) | 1775.0151 (177501.51 %) |

### H. DPEMDFML - ANN System Model - using EHRs Dataset - 75:25

In this study, the Artificial Neural Network (ANN) model was utilized to analyse the Electronic Health Records Dataset (EHRs Dataset). To ensure a rigorous evaluation of the model's capabilities, the dataset was split into 25% for testing, comprising 25,000 samples, and 75% for training, with 75,000 samples. The effectiveness of the ANN model was thoroughly assessed using two distinct evaluation tables: Table XXIII and Table XXIV, which offer a detailed view of the confusion matrix and facilitate an in-depth analysis of the model's performance.

During the training phase, Table XXIII depicts the predictions made by the ANN model for diabetes disease. The dataset used for training consists of 75,000 samples, which are further categorized into 6,409 real positive cases and 68,591 real negative cases. The model accurately identified 4,582 samples as truly positive, indicating the absence of healthcare issues. However, it misclassified 1,827 records as negatives,

falsely signalling the presence of a healthcare condition. Out of the 68,591 negative results, which indicate the presence of a healthcare condition, the model correctly forecasted 68,472 samples as negative, demonstrating its effectiveness in correctly identifying such cases. However, there were 119 samples that were inaccurately forecasted as positive, indicating the absence of a healthcare issue when it was present.

During the testing phase, Table XXIV presents the predictions made by the ANN model for diabetes disease. The dataset used for testing comprises 25,000 samples, which are further divided into 2,091 real positive cases and 22,909 real negative cases. The model accurately identified 1,461 samples as truly positive, indicating the absence of healthcare issues. However, it misclassified 630 records as negatives, falsely signaling the presence of a healthcare condition. Out of the 22,909 negative results, which indicate the presence of a healthcare condition, the model correctly forecasted 22,827 samples as negative, demonstrating its effectiveness in correctly identifying such cases. However, there were 82

samples that were inaccurately forecasted as positive, indicating the absence of a healthcare issue when it was present.

Table XXV provides a comprehensive summary of the ANN model's performance during the training phase, displaying various evaluation metrics. The ANN model achieved the following percentages for each metric: 97.40% for accuracy, 2.59% for miss-classification rate, 71.49% for sensitivity, 99.82% for specificity, 97.96% for precision, 0.17% for the False positive rate, 2.53% for the False discovery rate, 28.50% for the False omission rate, 41208.32% for the Positive likelihood ratio, 28.55% for the Negative likelihood ratio, 35.83% for the Prevalence threshold, 71.31% for the critical success index, 82.48% for the F1 Score, 82.25% for the Mathews Correlation coefficient, 97.09% for the Fowlkes-Mallows Index, 71.31% for informedness, and 144305.40% for the Diagnostic odds ratio. During the testing phase, the ANN model achieved the following percentages for each evaluation metric: 97.51% for accuracy, 2.84% for miss-classification rate, 69.87% for sensitivity, 99.64% for specificity, 94.68% for precision, 0.35% for the False positive rate, 5.51% for the False discovery rate, 30.12% for the False omission rate, 19520.38% for the Positive likelihood ratio, 30.23% for the Negative likelihood ratio, 35.11% for the Prevalence threshold, 69.51% for the critical success index,

80.40% for the F1 Score, 79.96% for the Mathews Correlation coefficient, 96.82% for the Fowlkes-Mallows Index, 69.51% for informedness, and 64557.19% for the Diagnostic odds ratio.

TABLE XXIII. ANN MODEL'S - EHRS DIABETES DATASET – TRAINING PHASE – 75:25

| Input | Total number of samples (75000) | Result (output) | |
|---|---|---|---|
| | Expected output | Predicted positive | Predicted negative |
| | 6409(positive) | 4582 (TP) | 1827 (FN) |
| | 68591 (negative) | 119 (FP) | 68472(TN) |

TABLE XXIV. ANN MODEL'S - EHRS DIABETES DATASET – TESTING PHASE – 75:25

| Input | Total number of samples (25000) | Result (output) | |
|---|---|---|---|
| | Expected output | Predicted positive | Predicted negative |
| | 2091(positive) | 1461 (TP) | 630 (FN) |
| | 22909(negative) | 82 (FP) | 22827 (TN) |

TABLE XXV. ANN MODEL'S (EHRS DIABETES DATASET) EVALUATION METRICS, 75:25

| | Testing | Training |
|---|---|---|
| Accuracy | 0.9715 (97.51 %) | 0.9740 (97.40 %) |
| Miss-classification rate | 0.0284 (2.84 %) | 0.0259 (2.59 %) |
| Sensitivity | 0.6987 (69.87 %) | 0.7149 (71.49 %) |
| Specificity | 0.9964 (99.64 %) | 0.9982 (99.82 %) |
| Precision | 0.9468 (94.68 %) | 0.9746 (97.96 %) |
| False positive rate | 0.0035 (0.35 %) | 0.0017 (0.17 %) |
| False discovery rate | 0.0531 (5.51 %) | 0.0253 (2.53 %) |
| false omission rate | 0.3012 (30.12 %) | 0.2850 (28.50 %) |
| Positive likelihood ration | 195.2038 (19520.38 %) | 412.0832 (41208.32 %) |
| Negative likelihood ratio | 0.3023 (30.23 %) | 0.2855 (28.55 %) |
| prevalence threshold | 0.3511 (35.11 %) | 0.3583 (35.83 %) |
| critical success index | 0.6951 (69.51 %) | 0.7131 (71.31 %) |
| F1 Score | 0.8040 (80.40 %) | 0.8248 (82.48 %) |
| Mathews Correlation co-efficient | 0.7996 (79.96 %) | 0.8225 (82.25 %) |
| Fowlkes-Mallows Index | 0.9682 (96.82 %) | 0.9709 97.09 %) |
| Informedness | 0.6951 (69.51 %) | 0.7131 (71.31 %) |
| Diagnostic odds ratio | 645.5719 (64557.19 %) | 1443.0540 (144305.40 %) |

The results of DPEMDFML model on the EHRs diabetes dataset indicate that the ANN model outperformed other algorithms in both the 70:30 and 75:25 ratio splits. With the 70:30 split, the ANN model achieved an impressive accuracy of 97.43%, showcasing its robustness in correctly classifying diabetes cases.

Similarly, in the 75:25 split, the ANN model maintained a high accuracy of 97.40%, further validating its effectiveness in handling the dataset. On the other hand, the SVM model also showcased commendable results on the same EHRs diabetes dataset. In the 70:30 split, the SVM model achieved an accuracy of 96.03%, demonstrating its potential to effectively classify diabetes cases.

In the 75:25 split, the SVM model maintained a high accuracy of 95.98%, further highlighting its capability to handle varying data proportions. Table XXVI show the accuracies reached in this study.

TABLE XXVI. PERFORMANCE OF PROPOSED DPEMDFML MODEL W.R.T PIMA DATASET AND EHRS DATASET

|  | PIMA dataset 70:30 | EHRs dataset 70:30 | PIMA dataset 75:25 | EHRs dataset 75:25 |
|---|---|---|---|---|
| *SVM* | 74.46 % | 96.03% | 78.81% | 95.98% |
| *ANN* | 90.13% | 97.43% | 90.97%, | 97.40% |

Table XXVII presented provides an overall comparison of the proposed DPEMDFML model with the previous works mentioned. The results clearly demonstrate that the accuracy of the proposed model has outperformed all the other accuracies reported in the mentioned works, using both of the employed algorithms.

TABLE XXVII. COMPARISON OF PROPOSED DPEMDFML MODEL WITH PREVIOUS WORKS MENTIONED

| Research Study | Method | Accuracy |
|---|---|---|
| Akkarapol and Jongsawas [11] |  | 77.11% |
| Kavakiotis et al. [12] |  | 84% |
| Xue-Hui Meng et al. [13] | • Logistic Regression Model <br> • Decision Tree Model (C5.0) <br> • Artificial Neural Networks (ANN) Model | 76.13% <br><br> 77.87% <br><br> 73.23% |
| Dey et al. [15] | • ANN Model with MMS | 82.35% |
| Proposed DPEMDFML model | • ANN <br> • SVM | 97.43% <br> 96.03% |

## VI. CONCLUSION

In summary, this research offers a distinctive and thorough investigation of the application of machine learning approaches for diabetes detection. The proposed DPEMDFML model shows improved accuracy in predicting diabetes disease compared to earlier efforts by using two separate algorithms and two different datasets. The comprehensive assessment

tables show that the SVM and ANN models performed well during both the testing and training periods. The suggested framework's use of machine learning fusion has the potential to diagnose diabetes earlier, resulting in proactive healthcare treatments and better patient outcomes. This work advances the field of diabetes diagnostic research by offering insightful information on the efficacy of various algorithms and datasets. The findings open the way for further study and model enhancement, with the goal of facilitating improved and more accurate diabetes detection in clinical situations. In future, we will incorporate more recent datasets to enhance the study's relevance and accuracy.

REFERENCES

[1] [Online]. Available: https://www.who.int/health-topics/diabetes#tab=tab_1.

[2] Katsarou, A., Gudbjörnsdottir, S., Rawshani, A., Dabelea, D., Bonifacio, E., Anderson, B. J. & Lernmark, A. Type 1 diabetes mellitus. Nature reviews Disease primers, vol. 3,no. 1, pp. 1-17, 2017.

[3] https://www.cdc.gov/diabetes/basics/prediabetes.html

[4] F. Islam, R. Ferdousi, S. Rahman, and H. Y. Bushra, Computer Vision and Machine Intelligence in Medical Image Analysis. London, U.K.: Springer, 2019

[5] Rehman, A., Athar, A., Khan, M. A., Abbas, S., Fatima, A., & Saeed, A. Modelling, simulation, and optimization of diabetes type II prediction using deep extreme learning machine. Journal of Ambient Intelligence and Smart Environments,vol. 12, no. 2, pp. 125-138, 2020.

[6] Joyia, G. J., Liaqat, R. M., Farooq, A., & Rehman, S. Internet of medical things (IoMT): Applications, benefits and future challenges in healthcare domain. J. Commun., vol. 12, no. 4, pp. 240-247, 2017.

[7] Muneer S, Rasool MA. A Enhancing Healthcare Outcomes with Explainable AI (XAI) for Disease Prediction: A Comprehensive Review. International Journal of Advanced Sciences and Computing, vol. 1, no. 1, pp. 37-42, 2022.

[8] Siddiqui, S. Y., Haider, A., Ghazal, T. M., Khan, M. A., Naseer, I., Abbas, S. & Ateeq, K. IoMT cloud-based intelligent prediction of breast cancer stages empowered with deep learning. IEEE Access, vol. 9, pp. 146478-146491, 2021.

[9] Jakkula, V. Tutorial on support vector machine (svm). School of EECS, Washington State University, vol. 37 no. 2, pp. 3-7, 2006.

[10] Boser, B. E., Guyon, I. M., & Vapnik, V. N.. A training algorithm for optimal margin classifiers. In Proceedings of the fifth annual workshop on Computational learning theory, pp. 144-152, 1992.

[11] Sa-ngasoongsong, A., & Chongwatpol, J. An analysis of diabetes risk factors using data mining approach. Oklahoma state university, USA, pp.1-55, 2012.

[12] Kavakiotis, I, Tsave, O., Salifoglou, A., Maglaveras, N., Vlahavas, I., & Chouvarda, I. Machine learning and data mining methods in diabetes research. Computational and Structural Biotechnology Journal, vol. 15, pp. -116, 2017.

[13] Meng, X. H., Huang, Y. X., Rao, D. P., Zhang, Q., & Liu, Q. Comparison of three data mining models for predicting diabetes or prediabetes by risk factors. The Kaohsiung Journal of Medical Sciences, vol. 29, no., pp. 93-99, 2013

[14] Muneer SM, Alvi MB, Farrakh A. Cyber Security Event Detection Using Machine Learning Technique. International Journal of Computational and Innovative Sciences, vol. 2, no. 2, pp. 42-46, 2023.

[15] Dey, S. K., Hossain, A., & Rahman, M. M. Implementation of a web application to predict diabetes disease: an approach using machine learning algorithm. In 2018 21st international conference of computer and information technology (ICCIT) IEEE, pp. 1-5, 2018.

[16] Pradhan, G., Pradhan, R., & Khandelwal, B. A study on various machine learning algorithms used for prediction of diabetes mellitus. In Soft Computing Techniques and Applications: Proceeding of the International Conference on Computing and Communication (IC3 2020) Springer Singapore, pp. 553-561, 2021.

[17] Abbas, T., Fatima, A., Shahzad, T., Alissa, K., Ghazal, T. M., Al-Sakhnini, M. M., & Ahmed, A. Secure IoMT for disease prediction empowered with transfer learning in healthcare 5.0, the concept and case study. IEEE Access, vol. 11, pp. 39418 – 39430, 2023.

[18] Abbas, S., Issa, G. F., Fatima, A., Abbas, T., Ghazal, T. M., Ahmad, M., & Khan, M. A. Fused Weighted Federated Deep Extreme Machine Learning Based on Intelligent Lung Cancer Disease Prediction Model for Healthcare 5.0. International Journal of Intelligent Systems, vol. 2023, pp. 1-15, 2023.

[19] Asif, R. N., Abbas, S., Khan, M. A., Sultan, K., Mahmud, M., & Mosavi, A. Development and validation of embedded device for electrocardiogram arrhythmia empowered with transfer learning. Computational Intelligence and Neuroscience, vol. 2022, pp. 1-14, 2022.

[20] Arooj, S., Zubair, M., Khan, M. F., Alissa, K., Khan, M. A., & Mosavi, A. Breast cancer detection and classification empowered with transfer learning. Frontiers in Public Health, vol. 10, pp. 1- 19, 2022.

[21] Khan, M. B. S., Nawaz, M. S., Ahmed, R., Khan, M. A., & Mosavi, A. Intelligent breast cancer diagnostic system empowered by deep extreme gradient descent optimization. Mathematical Biosciences and Engineering, vol. 19, no. 8, pp. 7978-8002, 2022.

[22] Ahmad, M., Alfayad, M., Aftab, S., Khan, M. A., Fatima, A., Shoaib, B., & Elmitwal, N. S. Data and Machine Learning Fusion Architecture for Cardiovascular Disease Prediction. Computers, Materials & Continua, vol. 69, no. 2, pp. 2717-2730, 2021.

[23] Siddiqui, S. Y., Naseer, I., Khan, M. A., Mushtaq, M. F., Naqvi, R. A., Hussain, D., & Haider, A. Intelligent breast cancer prediction empowered with fusion and deep learning. Computers, Materials and Continua, vol. 67, no. 1, pp. 1033-1049, 2021.

# A Comprehensive Comparative Study of Machine Learning Methods for Chronic Kidney Disease Classification: Decision Tree, Support Vector Machine, and Naive Bayes

Admi Syarif, Olivia Desti Riana, Dewi Asiah Shofiana, Akmal Junaidi

Department of Computer Science-Faculty of Mathematics and Natural Sciences, University of Lampung, Indonesia

*Abstract*—**Based on the findings of the 2010 Global Burden of Disease analysis, there was an increase in the global ranking of Chronic Kidney Disease (CKD) as a major contributor to mortality, moving from 27th place in 1990 to 18th position. Approximately 10 percent of the global population experiences CKD, and every year millions of lives are lost due to limited access to adequate treatment. CKD poses a substantial global health concern, greatly affecting both the well-being and life span of individuals afflicted by the condition. This study aims to evaluate the performance of three major classification algorithms in CKD diagnosis: Decision Tree, Support Vector Machine (SVM), and Naïve Bayes. This research distinguishes it from previous studies through an innovative data processing approach. Data preprocessing involved transforming categorical values into numerical form using label encoding, as well as applying Exploratory Data Analysis (EDA) to identify outliers and test data assumptions. In addition, the handling of missing values was done with appropriate strategies to maintain the integrity of the dataset. The classification method was evaluated using a dataset of 400 samples from Kaggle with 24 attributes. Through careful experimentation, the accuracy results of each algorithm are presented and compared. The results of this study can help in the development of a more efficient and accurate decision support system for the early diagnosis of CKD.**

*Keywords—Chronic kidney disease (CKD); classification; decision tree; machine learning; naïve bayes; support vector machine (SVM)*

## I. INTRODUCTION

The kidneys, a pair of bean-shaped organs, are located in the posterior part of the abdomen and play a major role in maintaining the body's internal balance. Their duties include filtering and purifying the blood, eliminating excess fluid and metabolic waste through the formation of urine, as well as regulating electrolyte balance, blood pressure, and the production of hormones that influence the formation of red blood cells. The central role of the kidneys in maintaining body harmony also supports the optimal performance of other organs [1].

Currently, the prevalence of CKD continues to increase globally and has become a serious health problem. Based on the Global Burden of Disease study in 2010, CKD rose to 18th as the world's leading cause of death, up from 27th in 1990. More than two million individuals worldwide undergo dialysis

therapy or kidney transplantation, although this number represents only about 10% of the population requiring such treatment. About ten percent of the global population suffers from CKD, and millions of lives are lost each year due to limited access to adequate treatment [2]. Chronic Kidney Disease (CKD) refers to the decline in kidney function that occurs slowly over months or even years [3]. Decreased kidney function can result in the accumulation of fluids, electrolytes, and metabolic waste in the body, which in turn causes various health problems.

In the early stages, CKD often does not cause noticeable symptoms, but patients may experience kidney pain when the disease is in an advanced stage [4]. Chronic kidney failure is progressive and cannot be cured, resulting in a high mortality rate. One of the problems faced by patients with CKD is the high cost of treatment and medication. Therefore, early detection is crucial to identify kidney disease at an early stage and prevent the development of chronic kidney disorders [5].

In the present era, the use of machine learning has become popular in the field of healthcare due to the demand for efficient analytical methodologies to uncover important yet undiscovered information in health data [6]. Medical data mining is employed to gain insights by reviewing information obtained from medical reports, evidence tables, flowcharts, research papers, and more. This data is then transformed into relevant information to support decision-making [7]. Machine learning is a field that encompasses the creation of statistical models and algorithms, empowering computer systems to execute tasks without direct commands, instead of relying on patterns and deduction. By using machine learning algorithms, computer systems can process large amounts of historical data and recognize patterns within that data. This allows the system to make more accurate predictions based on input data.

In this research, three machine learning classification methods are employed, specifically Decision Tree, Support Vector Machine, and Naïve Bayes. The difference from previous studies lies in the preprocessing stage, where several processing techniques are applied to the dataset. One of them is data transformation, where invalid values in categorical data are replaced and categorical values are converted to integers using label encoding. Furthermore, Exploratory Data Analysis (EDA) is conducted, employing descriptive statistics and visual tools to gain a deeper understanding of the data. The

goal of EDA is to uncover maximum insights from the dataset, identify outliers and anomalies, and test underlying assumptions [8]. The missing values are handled by filling in the mean for numerical attributes and the mode for categorical attributes. Additionally, k-fold cross-validation is employed to reduce the impact of accuracy instability. The accuracy is obtained from the average accuracy of each fold [9].

The objective of this research is to implement and evaluate Decision Tree, Support Vector Machine, and Naïve Bayes algorithms in the process of diagnosing CKD. The algorithm is implemented using the Python programming language. The study utilizes a dataset of 400 samples obtained from Kaggle, consisting of 24 attributes. The results of this research will be compared with previous studies to compare different classification methods and conclude the most effective classification.

The article is divided into several sections. In Section I, it covers the background, motivation, related work, and the overall structure of the article. This section provides an overview of the research context, the reasons behind conducting the study, and a review of relevant literature. Section II presents the related works, including the literature review. Section III present the workflow, CKD dataset. It discusses various steps such as preprocessing, handling missing values, Exploratory Data Analysis (EDA), *k*-fold

cross-validation, and the implementation of the decision tree, support vector machine, and Naïve Bayes algorithms. This section provides a comprehensive understanding of the dataset and the methodologies employed in the research. The experimental results of the decision tree, SVM, and Naïve Bayes methods in classifying CKD are presented in Section IV. This section evaluates the performance of each classification method and provides insights into their effectiveness in diagnosing the disease. Finally, Section V concludes the paper by summarizing the main findings, highlighting the research contributions, and offering recommendations for future studies.

## II. RELATED WORKS

Several studies have conducted the classification of CKD using machine learning methods. These are presented in Table I. Based on the information above, previous studies conducted data splitting using the split data function to divide the data into direct training and testing subsets. In this study, we employed the k-fold cross-validation method for data division, which can reduce instability in accuracy. The accuracy is calculated by averaging the accuracy of each fold. Furthermore, this study differed from previous research in terms of data pre-processing, as we applied several data processing techniques to the dataset.

TABLE I. PREVIOUS APPROACHES TO CHRONIC KIDNEY DISEASE

| Id | Authors | Data | Method | Results (Accuracy) |
|---|---|---|---|---|
| 1 | Senan et al. [10] | Data Name: Chronic Kidney Disease<br>Data Count: 400 patients<br>Attributes: 24<br>Source: University of California | SVM, K-NN, Random Forest. | SVM: 96.67%<br>K-NN: 98.33%<br>**Random Forest: 100%** |
| 2 | Saringat et al. [11] | Data Name: Chronic Kidney Disease<br>Data Count: 400 patients<br>Attributes: 25<br>Source: UCI Machine Learning Repository website | SVM, Decision Tree, K-NN, Regression. | SVM: 90.25%<br>Decision Tree: 95.50%<br>K-NN: 94.75%<br>**Regression: 98.25%** |
| 3 | Gokiladevi et al. [12] | Data Name: Chronic Kidney Disease<br>Data Count: 400 patients<br>Attributes: 24<br>Source: UCI Benchmark CKD | K-NN, SVM, Random Forest, Decision Tree, Logistic Regression. | K-NN: 67.50%<br>SVM: 73.75%<br>**Random Forest: 98.75%**<br>Decision Tree: 96.25%<br>Logistic Regression: 94.68% |
| 4 | Kumar et al. [13] | Data Name: Chronic Kidney Disease<br>Data Count: 400 patients<br>Attributes: 24<br>Source: University of California | Decision Tree,<br>Naive Bayes,<br>K-NN,<br>Random Forest, SVM. | Decision Tree: 94.00%<br>Naive Bayes: 93.00%<br>K-NN: 67.00%<br>**Random Forest: 97.00%**<br>**SVM: 97.00%** |
| 5 | Tekale et al. [14] | Data Name: Chronic Kidney Disease<br>Data Count: 400 patients<br>Attributes: 25<br>Source: UCI Repository | Decision Tree, SVM. | Decision Tree: 92.00%<br>**SVM: 97.00%** |
| 6 | Zeynu [15] | Data Name: Chronic Kidney Disease<br>Data Count: 400 patients<br>Attributes: 24<br>Source: UCI Repository | K-NN, ANN, Naïve Bayes, Ensamble model. | K-NN: 98.5%<br>ANN: 97.75%<br>Naïve Bayes: 94.5%<br>**Ensamble model: 99.00%** |
| 7 | Faddillah et al. [16] | Data Name: Chronic Kidney Disease<br>Data Count: 400 patients<br>Attributes: 24<br>Source: Indians Chronic Kidney Disease | Naive Bayes. | Naive Bayes: 91.25% |
| 8 | Amalia [17] | Data Name: Chronic Kidney Disease<br>Data Count: 400 patients<br>Attributes: 24<br>Source: UCI Repository | SVM, NN. | **SVM: 95.16%**<br>NN: 93.36% |

| 9 | Ariani & Samsuryadi [18] | Data Name: Chronic Kidney Disease<br>Data Count: 400 patients<br>Attributes: 24<br>Source: UCI Repository Machine Learning Benchmark | K-NN | K-NN: 85.83% |

## III. METHODS

This research involves several stages in analyzing the performance of CKD classification methods. The process begins with a literature review. The second stage involves collecting the CKD dataset. The third stage is the preprocessing stage, where data transformation, missing value handling, and Exploratory Data Analysis (EDA) are performed. Next is the data partitioning stage, using *k*-fold cross-validation. The subsequent stage involves building the model and finally evaluating the model using a confusion matrix and comparing the results. The stages of analyzing the CKD classification process in this research are illustrated in Fig. 1 below:
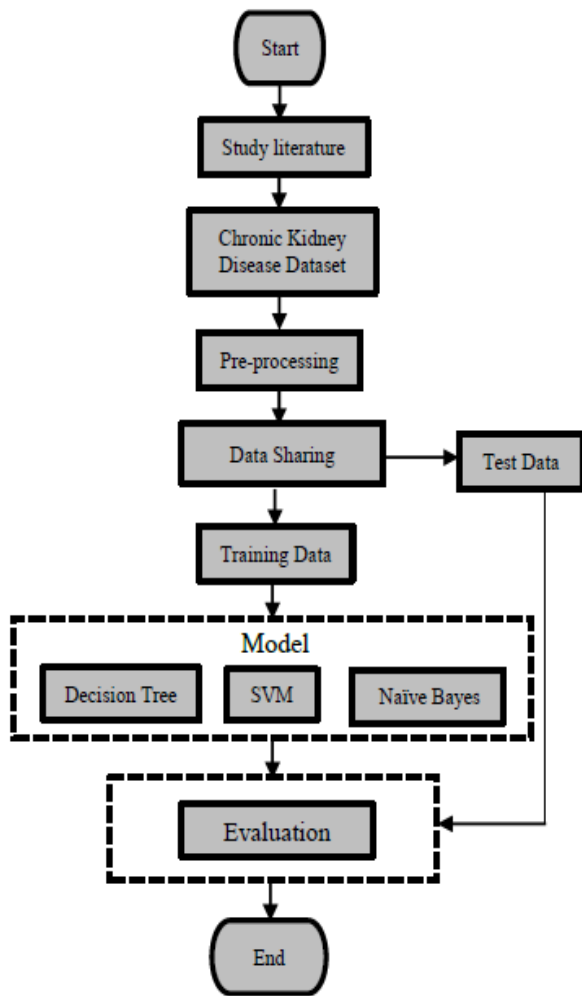


Fig. 1. The research workflow.

### A. Dataset

The study utilized data obtained from Kaggle, originating from a Kaggle account created by Nitesh Yadav, a Data Science Intern Technologies from India. The dataset consists of 400 instances with 24 attributes, presented in CSV format.

Table II thoroughly describes the attributes related to CKD, providing a comprehensive understanding of the variables involved. By utilizing this dataset, the study aims to analyze and uncover insights regarding the relationships between these attributes and the occurrence of the disease.

TABLE II. DATA FOR CHRONIC KIDNEY DISEASE

| Attribute | Possible Values | Types |
|---|---|---|
| Age | Years | Numeric |
| Blood Pressure | mm/Hg | Numeric |
| Specific Gravity | 1.005,1.010,1.015,1.020,1.025 | Nominal |
| Albumin | 0,1,2,3,4,5 | Nominal |
| Sugar | 0,1,2,3,4,5 | Nominal |
| Red Blood Cells | normal, abnormal | Nominal |
| Pus cells | normal, abnormal | Nominal |
| Pus Cell Clumps | present, not present | Nominal |
| Bacteria | present, not present | Nominal |
| Blood Glucose Random | mg/dl | Numeric |
| Blood Urea | mg/dl | Numeric |
| Serum Creatinine | mg/dl | Numeric |
| Sodium | mEq/L | Numeric |
| Potassium | mEq/L | Numeric |
| Hemoglobin | gms | Numeric |
| Packed Cell Volume | - | Numeric |
| White Blood Cell Count | cells/cumm | Numeric |
| Red Blood Cell Count | millions/cm | Numeric |
| Hypertension | yes, no | Nominal |
| Diabetes Mellitus | yes, no | Nominal |
| Coronary Artery Disease | yes, no | Nominal |
| Appetite | good, poor | Nominal |
| Pedal Edema | yes, no | Nominal |
| Anemia | yes, no | Nominal |
| Classification | ckd, not ckd | Nominal |

### B. Pre-processing

*1) Data transformation:* Incorrect or misleading analysis can occur if there are duplicates or missing data. Therefore, the pre-processing stage plays a crucial role in preparing high-quality data, resulting in more accurate and reliable decisions [19]. In this study, several preprocessing steps were performed on the dataset, including data transformation. During this stage, invalid values in the diabetes mellitus, coronary artery disease, and class attributes were modified. Detailed changes

are recorded in Table III, providing a clear overview of the transformations applied. Through the execution of these data transformations, the dataset gains enhanced accuracy and become well-prepared for subsequent phases of analysis and modeling. Furthermore, to translate categorical attributes into a numerical format, label encoding is employed. In this context, since all categorical attributes have two categories, label encoding can be employed to convert these categorical values into integers, namely 0 and 1.

TABLE III.    DATA TRANSFORMATION

| Attribute | Transformation |
|---|---|
| Diabetes mellitus | \tno = no; \tyes = yes; yes=yes |
| Coronary artery disease | \tno = no |
| class | ckd\t = ckd; notckd = not ckd |

*2) Missing value handling:* Machine learning models can encounter errors if the dataset contains missing data that is not handled properly. When the dataset is small, discarding samples with missing data is not an appropriate option, as it can reduce the amount of data used to train the machine learning model and affect the accuracy of data analysis. To address this issue, a technique called "Missing Value Handling" is used to handle missing data by filling in appropriate values based on the characteristics of the samples. By filling in the missing data, the dataset can be used to train the machine learning model, resulting in a well-trained model with optimal performance [20]. In this study, the missing data is filled in using the mean and mode values. The mean value is used to fill in missing data in numerical attributes, while the mode value is used to fill in missing data in categorical attributes.

*3) Exploratory Data Analysis (EDA):* Exploratory Data Analysis (EDA) is a critical procedure encompassing the recognition and description of repetitive patterns, noteworthy correlation arrangements, and the discernment of variables responsible for noteworthy diversity within a reduced dimensional framework. Moreover, EDA aids in the detection of anomalies like outliers, which might point to potential problems with data quality. It plays a crucial role in understanding the data by uncovering hidden patterns, exploring relationships between variables, and identifying redundant features. EDA serves as an important step in data exploration, enabling researchers to gain insights, make informed decisions, and provide a solid foundation for subsequent analysis and modeling [21].

### C. Data Sharing

Within this study, the process of data division is executed through *k*-fold cross-validation. This technique encompasses a series of validation trials where training, validation, and testing phases are carried out. In the initial trial, 80% of datasets chosen at random were employed for training, leaving the remaining 20% for testing purposes. In the subsequent trial, a wholly distinct set of datasets, comprising 80% of the

total, is employed for training, while the residual 20% serves for testing purposes. This process is repeated with different sets of 80% training datasets and 20% testing datasets, as shown in Fig. 2, where a total of five experiments are conducted sequentially. Assuming that the selection of training and testing datasets is truly random and the *k*-fold cross-validation process is ergodic, the correct output is obtained by averaging the outputs of all the experiments [9].

| Experiment 1 | *Test* | *Train* | *Train* | *Train* | *Train* |
|---|---|---|---|---|---|
| Experiment 2 | *Train* | *Test* | *Train* | *Train* | *Train* |
| Experiment 3 | *Train* | *Train* | *Test* | *Train* | *Train* |
| Experiment 4 | *Train* | *Train* | *Train* | *Test* | *Train* |
| Experiment 5 | *Train* | *Train* | *Train* | *Train* | *Test* |

Fig. 2.    K-Fold cross validation.

### D. Decision Tree

A conventional tree is composed of a root, branches, and leaves. Similarly, the structure of a Decision Tree includes a root node, branches, and leaf nodes. At each internal node, an attribute is subjected to testing, and the test outcome guides the branch selection, ultimately leading to the assignment of a class label to the corresponding leaf node. Positioned at the highest level, the root node functions as the progenitor of all nodes within the tree. A Decision Tree presents a hierarchical representation where each node signifies a feature (attribute), each link (branch) embodies a decision (rule), and each leaf encapsulates an outcome (categorical or continuous value). Because Decision Trees mimic human cognitive processes, they provide an intuitive means of grasping data and deriving insightful interpretations. The overarching idea is to construct such a tree for the complete dataset, yielding a distinct outcome at each leaf [22].

### E. Support Vector Machine

SVM operates as a learning mechanism featuring a hypothesis space founded on linear functions within a feature space of significant dimensions. Its training is facilitated by learning algorithms rooted in optimization theory principles. The accuracy level achieved by the SVM model is highly dependent on the kernel function and parameters used during the training process. Based on its characteristics, the SVM method can be divided into two types: Linear SVM and Non-linear SVM. Linear SVM separates data linearly by placing a hyperplane with a soft margin between classes. The illustration of the linear SVM can be seen in Fig. 3. On the other hand, Non-linear SVM implements the kernel trick by mapping the data into a higher-dimensional space [23]. Basically, the concept of SVM involves finding the optimal separator on the hyperplane, as shown in Fig. 4. The best-separating hyperplane is determined by searching for the value of *f(x)* on the hyperplane margin [24-26].
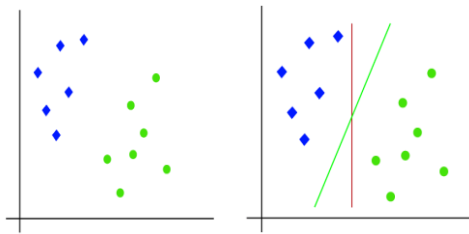
Fig. 3.    Linear SVM [25].
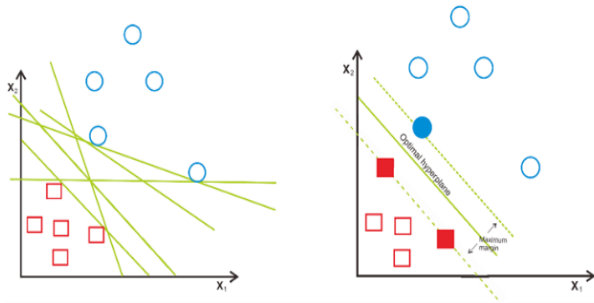


Fig. 4.    The effort to find the best hyperplane [26].

### F. Naïve Bayes

Naive Bayes classification employs the principle of maximum likelihood estimation to categorize samples into the most probable groups [27]. Given an input vector with features represented as *X* and a class label denoted as *Y*, the concept of Naive Bayes is symbolized by *P(Y/X)*, indicating the probability of class label Y considering the observed features *X*. This representation signifies the posterior probability of *Y*. The original probability *P(Y)*, recognized as the prior probability, is also considered. Throughout the training phase, the task involves acquiring knowledge about the posterior probabilities (*P(Y/X)*) for every combination of *X* and *Y* using insights gleaned from the training dataset [28].

### G. Evaluation Metrics

The assessment conducted in this study employs a Confusion Matrix. The Confusion Matrix serves as a performance evaluation tool for machine learning classification tasks encompassing two or more classes. This table showcases various combinations of projected and actual values. Comprising four terms, the Confusion Matrix outlines the classification outcomes: True Positive, True Negative, False Positive, and False Negative [29]. True Positive (TP) signifies accurate positive predictions, while True Negative (TN) signifies accurate negative predictions. False Positive (FP) relates to an erroneous positive prediction, whereas False Negative (FN) corresponds to an incorrect negative prediction. The Confusion Matrix entails several computations, including:

Accuracy measures how accurately a model classifies data correctly [29]. The calculation of accuracy is done using by using Eq. (1).

$$\text{Accuracy} = \frac{(TP+TN)}{(TP+FP+FN+TN)} \times 100\% \qquad (1)$$

Precision describes the accuracy between the requested data and the predicted results given by the model [29]. The calculation of Precision is done using Eq. (2).

$$\text{Precision} = \frac{(TP)}{(TP+FP)} \times 100\% \qquad (2)$$

Recall or Sensitivity represents the success of the model in capturing information [29]. The calculation of Recall or Sensitivity is done using Eq. (3).

$$\text{Recall} = \frac{TP}{(TP+FN)} \times 100\% \qquad (3)$$

*F*-1 Score represents the weighted average of Precision and Recall. Accuracy is used as a performance reference for algorithms when the dataset has a significant number of false negatives and false positives. However, if the numbers are not close, the *F*-1 Score is used as a study in [29]. The calculation of the F-1 Score is done using Eq. (4).

$$F-1 \text{ Score} = 2x \frac{(\text{Recall x Precision})}{(\text{Recall+Precision})} \times 100\% \qquad (4)$$

### IV.    EXPERIMENTS AND RESULTS

In this study, we utilized the laptop on the Windows 10 64-bit operating system with 8 GB of memory. It is powered by an Intel(R) Core (TM) i5-4210U processor, which provides processing capabilities ranging from 1.70 GHz to 2.39 GHz. The software employed for the study includes Python 3.10.6, Anaconda Navigator, Jupiter Notebook, a web browser, and Microsoft Excel. These tools and technologies formed the computational environment in which the analyses and experiments were conducted.

For the experiments, the data is divided by using used 5-Fold cross validation (80% data for training and 20% data for testing). The following Table IV presents the comparison of the method for each fold.

TABLE IV.    THE VALUE OF K-FOLD CROSS-VALIDATION IN A MODEL

| Fold | Decision Tree | Support Vector Machine | Naïve Bayes |
|---|---|---|---|
| | | Accuracy | |
| 1 | 0.975 | 0.9625 | 1.00 |
| 2 | 0.9875 | 0.975 | 0.975 |
| 3 | 0.95 | 0.95 | 0.925 |
| 4 | 0.975 | 1.0 | 0.95 |
| 5 | 0.9875 | 1.0 | 0.9375 |
| **Average** | **0.975** | **0.9775** | **0.9575** |

TABLE V.    CONFUSION MATRIX DECISION TREE

| Class | Positive predicted | Negative predicted |
|---|---|---|
| Positive actual | 245 | 5 |
| Negative actual | 5 | 145 |

In the above Table V, we show the confusion matrix to decision tree. There are 245 instances of true positives (TP), representing cases that truly belong to the positive class of CKD and are accurately identified as such by the CKD prediction. There are five false positives (FP), which are samples that actually belong to the positive class of having

CKD but are incorrectly predicted as negative for CKD. There are five false negatives (FN), which are samples that actually belong to the negative class but are incorrectly predicted as positive. There are 145 true negatives (TN),

TABLE VI.    CONFUSION MATRIX FOR SVM

| Class | Positive predicted | Negative predicted |
|---|---|---|
| Positive actual | 246 | 4 |
| Negative actual | 5 | 145 |

Table VI presents the confusion matrix for support vector machine. There are 246 true positives (TP), which are samples that actually belong to the positive class of having CKD and are correctly predicted as positive for CKD. There are four false positives (FP), which are samples that actually belong to the positive class of having CKD but are incorrectly predicted as negative for CKD. There are five false negatives (FN), which are samples that actually belong to the negative class but are incorrectly predicted as positive for CKD. There are 145 true negatives (TN).

The above Table VII shows the confusion matrix for naïve Bayes, there are 233 true positives (TP. There are 17 false positives (FP), which are samples that actually belong to the positive class of having CKD but are incorrectly predicted as negative for CKD. There are 0 false negatives (FN), which means there are no samples that actually belong to the negative class of not having CKD but are incorrectly predicted as positive for CKD. There are 150 true negatives (TN), which are samples that actually belong to the negative class of not having CKD and are correctly predicted as negative for CKD.

Table VIII presents the comparison of these three models. It is shown that the SVM method performs exceptionally well, exhibiting excellent precision, recall, F1-score, and accuracy, making it highly reliable for diagnosing CKD. The Naïve Bayes method yields good results, although slightly lower than SVM and Decision Tree in some metrics, with high precision, but a slightly lower recall. However, the Naïve Bayes method still demonstrates good overall performance with a relatively high F1-score and accuracy in predicting CKD. All three methods show satisfactory performance in diagnosing CKD, with the SVM method standing out as the most accurate.

Finally, here, we also compared our results with those of previous studies. We summarize the comparison in Fig. 5.

TABLE VII.    CONFUSION MATRIX NAÏVE BAYES

| Class | Positive predicted | Negative predicted |
|---|---|---|
| Positive actual | 233 | 17 |
| Negative actual | 0 | 150 |

TABLE VIII.    THE COMPARISON OF THE METHODS

| Method | Precision | Recall | F1-score | Accuracy |
|---|---|---|---|---|
| Decision Tree | 0.97 | 0.97 | 0.97 | 0.97 |
| SVM | 0.98 | 0.98 | 0.98 | 0.98 |
| Naïve Bayes | 0.96 | 0.96 | 0.96 | 0.96 |
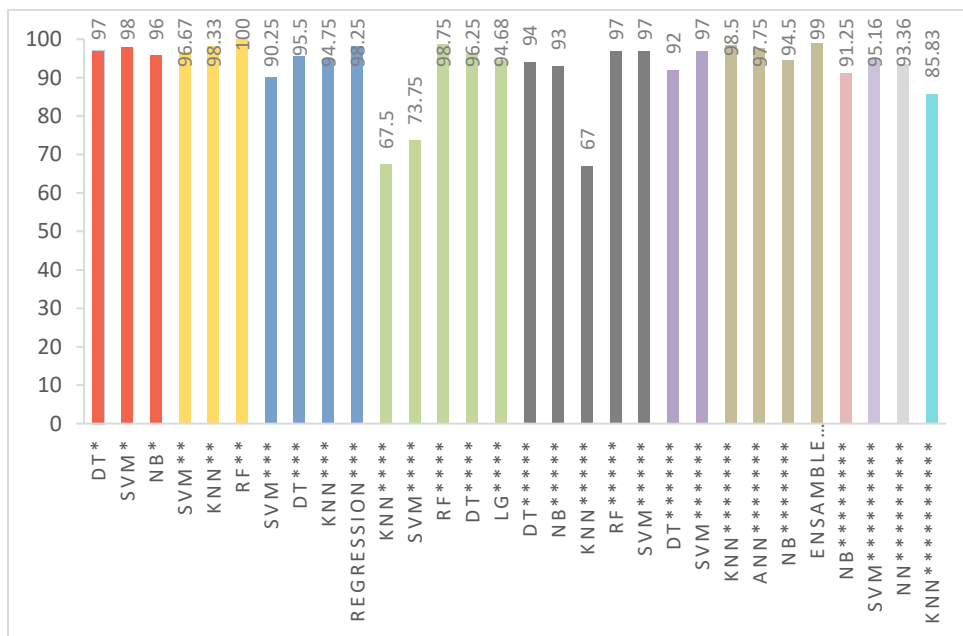


Fig. 5.    Comparison graph with several previous studies.

Description :

*/ This research
**/ [10]
***/ [11]
****/ [12]
*****/ [13]

******/ [14]
*******/ [15]
********/ [16]
*********/ [17]
**********/ [18]

## V. CONCLUSION AND FUTURE WORKS

### A. Conclusion

Through meticulous implementation, we successfully applied three major classification algorithms in the CKD diagnosis process, namely Decision Tree, Support Vector Machine (SVM), and Naïve Bayes. The analysis of the results confirms that all three methods have exhibited exceptional performance in predicting the disease. Notably, the most intriguing outcome is the achievement of the highest accuracy rate by the Support Vector Machine (SVM) method, reaching a score of 0.98. Thus, this research not only provides deeper insights into early diagnosis and CKD management but also offers valuable guidance in utilizing the most effective classification algorithms for this condition.

### B. Recommendations

The recommendations provided in this study are as follows:

*1)* For future research, it is suggested to explore newer classification methods such as deep learning or ensemble learning. The use of more complex classification methods, may provide advantages in diagnosing CKD.

*2)* Future studies could utilize larger datasets encompassing a wider attribute range. This will aid in better analyzing the performance of classification methods. Additionally, considering data from other sources to supplement the analysis could be beneficial.

### ACKNOWLEDGMENT

### REFERENCES

[1] H. Kusuma and Suhartini, "Understanding Chronic Kidney Disease and its Treatment." Semarang: Faculty of Medicine, Diponegoro University, 2019.

[2] Aulia, "Chronic Kidney Disease," p2ptm.kemkes.go.id, 2017.

[3] Ministry of Health Indonesia (Kemenkes RI), "What Are the Functions of the Kidneys?," p2ptm.kemkes.go.id, 2019.

[4] Ministry of Health Indonesia (Kemenkes RI), "Symptoms of Chronic Kidney Disease Often Go Unnoticed, Suddenly Stage 5," www.kemkes.go.id, 2023.

[5] Sehat Negriku Sehat Bangsaku, "Maintaining Healthy Kidneys," sehatnegeriku.kemkes.go.id, 2016.

[6] S. F. Sung, P. J. Lee, C. Y. Hsieh, and W. L. Zheng, "Medication use and the risk of newly diagnosed diabetes in patients with epilepsy: A data mining application on a healthcare database," J. Organ. End User Comput., vol. 32, no. 2, pp. 93–108, 2020, doi: 10.4018/JOEUC.2020040105.

[7] S. Kiruthika Devi, S. Krishnapriya, and D. Kalita, "Prediction of heart disease using data mining techniques," Indian J. Sci. Technol., vol. 9, no. 39, 2016, doi: 10.17485/ijst/2016/v9i39/102078.

[8] M. Batta, "Machine Learning Algorithms - A Review," Int. J. Sci. Res., vol. 18, no. 8, pp. 381–386, 2018, doi: 10.21275/ART20203995.

[9] F. Y. H. Ahmed, Y. H. Ali, and S. M. Shamsuddin, "Using K-fold cross validation proposed models for SpikeProp learning enhancements," Int. J. Eng. Technol., vol. 7, no. 4, pp. 145–151, 2018, doi: 10.14419/ijet.v7i4.11.20790.

[10] E. M. Senan, "Diagnosis of Chronic Kidney Disease Using Effective Classification Algorithms and Recursive Feature Elimination Techniques," J. Healthc. Eng., vol. 2021, 2021, doi: 10.1155/2021/1004767.

[11] Z. Saringat, A. Mustapha, R. D. R. Saedudin, and N. A. Samsudin, "Comparative analysis of classification algorithms for chronic kidney disease diagnosis," Bull. Electr. Eng. Informatics, vol. 8, no. 4, pp. 1496–1501, 2019, doi: 10.11591/eei.v8i4.1621.

[12] M. Gokiladevi, S. Santhoshkumar, and V. Varadarajan, "Machine Learning Algorithm Selection for Chronic Kidney Disease Diagnosis and Classification," Malaysian J. Comput. Sci., vol. 2022, no. Special Issue 1, pp. 102–115, 2022, doi: 10.22452/mjcs.sp2022no1.8.

[13] S. Kumar and Mohammad, "Intelligent Systems with Applications Chi 2 -MI: A hybrid feature selection based machine learning approach in the diagnosis of chronic kidney disease," Intell. Syst. with Appl., vol. 16, no. October, p. 200144, 2022, doi: 10.1016/j.iswa.2022.200144.

[14] S. Tekale, P. Shingavi, S. Wandhekar, and A. Chatorikar, "Prediction of Chronic Kidney Disease Using Machine Learning Algorithm," no. October 2018, 2022, doi: 10.17148/IJARCCE.2018.71021.

[15] S. Zeynu, "Prediction of Chronic Kidney Disease Using Data Mining Feature Selection and Ensemble Method," vol. 15, pp. 168–176, 2018.

[16] A. N. Faddillah, J. Wijaya, and R. Hidayat, "Application of Naive Bayes Algorithm for the Diagnosis of Chronic Kidney Disease," J. Inf., vol. 18, no. 2, pp. 102–106, 2019, doi: 10.36054/jict-ikmi.v18i2.69.

[17] H. Amalia, "Comparison of Data Mining Methods SVM and NN for the Classification of Chronic Kidney Disease," vol. 14, no. 1, pp. 1–6, 2018.

[18] A. Ariani and Samsuryadi, "Classification of Chronic Kidney Disease Using K-Nearest Neighbor," Annual Research Seminar Proceedings, vol. 5, no. 1, pp. 148–151, 2019.

[19] H. Yang, "Data Preprocessing-Chapter 3," Citeseerx, 2013.

[20] R. A. Maula and Gunawan, "Handling Missing Value with Regression Approach in Small-Scale Aquaculture Dataset," J. Rekayasa Elektr., vol. 18, no. 3, pp. 175–184, 2022, doi: 10.17529/jre.v18i3.25903.

[21] V. Da Poian and B. Theiling, "Exploratory Data Analysis (EDA) Machine Learning Approaches for Ocean World Analog Mass Spectrometry," Front. Astron. Sp. Sci., vol. 10, no. May, pp. 1–17, 2023, doi: 10.3389/fspas.2023.1134141.

[22] H. H. Patel and P. Prajapati, "Study and Analysis of Decision Tree Based Classification Algorithms," Int. J. Comput. Sci. Eng., vol. 6, no. 10, pp. 74–78, 2018, doi: 10.26438/ijcse/v6i10.7478.

[23] A. M. Puspitasari, D. E. Ratnawati, and A. W. Widodo, "Classification of Oral and Dental Diseases Using Support Vector Machine Method," J-Ptiik, vol. 2, no. 2, pp. 802–810, 2018.

[24] E. A. Kurnianto, I. Cholissodin, and E. Santoso, "Classification of Chronic Kidney Disease Patients Using Support Vector Machine (SVM) Algorithm," J. Pengemb. Teknol. Inf. dan Ilmu Komput. Univ. Brawijaya, vol. 2, no. 12, pp. 6597–6602, 2018.

[25] Trivusi, "Complete Explanation of Support Vector Machine (SVM) Algorithm," trivusi.web.id, 2022.

[26] A. P. Wibawa, M. G. A. Akbar, P. M. Fathony, and F. A. Dwiyanto, "metode metode klasifikasi.pdf," Proceedings of the Seminar on Computer Science and Information Technology, vol. 5, 2018.

[27] H. Chen, S. Hu, R. Hua, and X. Zhao, "Improved Naive Bayes Classification Algorithm for Traffic Risk Management," EURASIP J. Adv. Signal Process., vol. 2021, no. 1, 2021, doi: 10.1186/s13634-021-00742-6.

[28] E. Prasetyo, R. A. D. Rahajoe, and A. Arizal, "Comparison of K-Support Vector Nearest Neighbour and Decision Tree to Naive Bayes," National Seminar on Information Technology Proceedings, pp. 1–6, 2013.

[29] M. S. Anggreany, "Confusion Matrix," socs.binus.ac.id, 2022.

# Deep Convolutional Neural Network for Accurate Prediction of Seismic Events

Assem Turarbek[1], Maktagali Bektemesov[2], Aliya Ongarbayeva[3], Assel Orazbayeva[4],

Aizhan Koishybekova[5], Yeldos Adetbekov[6]

Al-Farabi Kazakh National University, Almaty, Kazakhstan[1, 6]
Abai Kazakh National Pedagogical University, Almaty, Kazakhstan[2]
Kazakh National Women's Teacher Training University, Almaty, Kazakhstan[3]
Zhetysu University named after I. Zhansugurov, Taldykorgan, Kazakhstan[4, 5]

*Abstract*—In recent years, the realm of seismology has witnessed an increased integration of advanced computational techniques, seeking to enhance the precision and timeliness of earthquake predictions. The paper titled "Deep Convolutional Neural Network and Machine Learning Enabled Framework for Analysis and Prediction of Seismic Events" embarks on an ambitious exploration of this interstice, marrying the formidable prowess of Deep Convolutional Neural Networks (CNNs) with an array of machine learning algorithms. At the forefront of our investigation is the Deep CNN, known for its unparalleled capability to process spatial hierarchies and multi-dimensional seismic data. Accompanying this neural behemoth is LightGBM, a gradient boosting framework that offers superior speed and performance, especially with voluminous datasets. Additionally, conventional neural networks, noted for their adeptness in pattern recognition, offer a robust method to gauge the intricacies of seismic data. Our exploration doesn't halt here; the research delves deeper with Random Forest and Support Vector Machines (SVM), both renowned for their resilient performance in classification tasks. By amalgamating these diverse methodologies, this research crafts a multifaceted and synergistic framework. The culmination is a sophisticated tool poised to not only discern the minutiae of seismic activities with heightened accuracy but to predict forthcoming events with a degree of certainty previously deemed elusive. In this era of escalating seismic activities, our research offers a timely beacon, heralding a future where communities are better equipped to respond to the Earth's capricious tremors.

*Keywords—Deep learning; CNN; random forest; SVM; neural network; prediction; analysis*

## I. INTRODUCTION

Seismology, the scientific study of earthquakes and the propagation of elastic waves through the Earth, stands at a critical juncture of its evolution. Historically, the analysis and prediction of seismic events leaned heavily on manual observation, conventional statistical methods, and rudimentary computational models [1]. The challenge inherent to these traditional approaches was their inability to fathom the vast intricacy of geological phenomena at multiple scales, from the minute shifts deep within the Earth's crust to grand tectonic movements that drive seismic activity [2]. Furthermore, the limitations of early computational tools were often a bottleneck, unable to cope with the sheer volume and complexity of seismic data.

In the 21st century, a transformative shift is underway. The information age, characterized by the rise of big data and advanced computational models, is ushering in a new era for seismological research [3]. The nexus of this transformation is the integration of machine learning (ML) and deep learning algorithms, poised to revolutionize the manner in which we perceive, analyze, and predict seismic events [4]. No longer are we solely dependent on conventional methods that, albeit valuable, offered limited insights and predictive capabilities. Instead, we're at the dawn of an era where artificial intelligence (AI) powered models promise a quantum leap in our understanding and preparedness for seismic activities.

Central to this shift is the Deep Convolutional Neural Network (CNN) [5]. Originally designed for image and video recognition tasks, CNNs have demonstrated an uncanny aptitude for handling spatial hierarchies and multi-dimensional datasets, making them particularly well-suited for seismic data interpretation [6]. These networks are adept at autonomously extracting pertinent features from vast datasets, making them invaluable tools in the realm of seismology where data is both abundant and complex.

The story doesn't end with CNNs. LightGBM, a gradient boosting framework, is emerging as another significant contender [7]. With its inherent ability to handle large datasets and its unique leaf-wise growth strategy, LightGBM offers speed and performance benefits that are often superior to other gradient boosting algorithms. Its capacity to work with categorical features directly, without the need for extensive preprocessing, makes it a potent tool for seismic data, which often exhibits categorical variances.

Neural networks, the precursors to more advanced deep learning models like CNNs, are also significant players [8]. Their design, inspired by the neural structure of the human brain, has proven effective in pattern recognition tasks for decades [9]. In the context of seismology, these networks are especially beneficial when tasked with discerning patterns within seismic waveforms and other related datasets.

Supplementing the above models are two stalwarts of the machine learning community: Random Forest and Support Vector Machines (SVM) [10]. Random Forest, an ensemble learning method, is renowned for its ability to handle large data sets with higher dimensionality, offering insights through its multitude of decision trees. SVM, on the other hand, has

carved its niche in classification and regression tasks, especially when the focus is on ensuring a clear margin of separation between classes.

The integration of these diverse methodologies into seismological research is not merely an academic exercise. Earthquakes have been, and continue to be, a significant threat to human civilizations. Their unpredictability and potential for destruction underscore the urgency for improved prediction and analysis tools [11]. Every stride made in enhancing the accuracy and timeliness of earthquake predictions translates to invaluable minutes that can save lives, reduce injuries, and mitigate property damage.

This paper seeks to weave together these threads of innovation. By harmonizing advanced computational models with traditional seismological knowledge, our research endeavors to construct a comprehensive framework. This synthesis aims to offer enhanced analytical power, deeper insights into seismic events, and, crucially, the ability to predict upcoming tremors with a level of confidence that was previously beyond reach.

In the ensuing sections, we will delve into the mechanics of each of these methodologies, elucidate their integration into our proposed framework, and present empirical evidence showcasing the efficacy of our approach. The journey will be both technical and enlightening, but it serves a singular, profound purpose: equipping humanity with better tools to understand, predict, and thus respond to the unpredictable fury of Mother Earth.

## II. RELATED WORKS

The integration of computational models into seismology is not a novel endeavor. Over the years, a plethora of research has sought to harness the power of computational algorithms to decode the enigmatic nature of seismic events. In this section, we delve into seminal works and research endeavors that have paved the way for the current study, tracing the trajectory of innovations from rudimentary tools to the sophisticated methodologies employed today.

### A. Traditional Seismic Analysis Methods

In the annals of seismological study, traditional seismic analysis methods remain invaluable, representing the foundational bedrock upon which subsequent innovations have been built [12]. These methods predominantly hinge upon deterministic approaches, closely anchored to direct observations and empirical correlations derived from a myriad of recorded seismic events. One of the seminal contributions in this area which painstakingly delineates the characteristics and intricacies of ground motion models [13]. These models, crucially, elucidate the manner in which seismic waves propagate through diverse geological strata, factoring in variables like wave amplitude, frequency, and phase velocity. Notably, the primary emphasis of these classical models was to capture and represent the physical processes underpinning seismic wave propagation, ranging from the genesis of the seismic event to its subsequent transmission across the Earth's crust. However, a notable limitation of these traditional methods was their inherent reliance on discrete data points and manual feature extraction. While they provided a granular understanding of seismic phenomena, they often grappled with the challenges posed by the complexity and variability of real-world seismic activities. In essence, traditional seismic analysis methods, while foundational, paved the way for the integration of more sophisticated computational tools, championing the nexus between geophysical understanding and computational prowess [14].

### B. Neural Networks in Seismology

The incorporation of neural networks into seismology marked a transformative juncture, heralding the fusion of artificial intelligence with geophysical inquiry. Historically, the seismic domain, dense with intricate data patterns, posed analytical challenges that often superseded the capabilities of traditional algorithms. It was within this milieu that the potential of neural networks emerged as a beacon of promise. One of studies in this area stands testament to this, where they employed feedforward neural networks to discern intricate seismic patterns, drawing associations often imperceptible to rudimentary algorithms [15]. This was not merely about detection; it was an exercise in understanding, categorizing, and predicting seismic anomalies with heightened accuracy. Another landmark study [16] built upon this foundation, harnessing neural networks for the intricate task of phase picking, a critical element in delineating the temporal attributes of seismic waves. The profound advantage of neural networks lay in their adaptive learning capabilities, autonomously refining their models based on the depth and breadth of data they encountered. Thus, neural networks did not just represent a tool; they signified an evolutionary leap in the computational analysis of seismology, laying the groundwork for further innovations in the domain.

### C. Random Forest and Earthquake Detection

With the proliferation of data-intensive seismological studies, the quest for robust analytical tools capable of handling multifaceted seismic datasets became paramount. This underscored the emergence of the Random Forest algorithm within the seismological realm, championing a more holistic and ensemble-driven approach to earthquake detection [17]. The essence of Random Forest, as an ensemble learning methodology, lies in its ability to construct a multitude of decision trees during training and outputting the mode of the classifications for classification tasks. Nikoobakht et al. (2022) presented a seminal exploration into the efficacy of Random Forest in earthquake early warning systems [18]. Their study accentuated the algorithm's adeptness at distinguishing seismic signals from background noise, a crucial facet in timely earthquake detection and alert dissemination. Notably, the Random Forest's inherent capacity to handle high-dimensional data, coupled with its resilience against overfitting, distinguished it from its computational counterparts [19]. Furthermore, its facility to offer importance scores for features provided invaluable insights into the most salient seismic indicators. Collectively, the introduction and adoption of the Random Forest algorithm in seismic studies signaled a strategic shift towards ensemble-based methodologies, aiming for increased accuracy and predictability in earthquake detection endeavors.

## D. SVM in Seismic Event Classification

Support Vector Machines (SVM), a class of supervised learning algorithms, have steadily emerged as pivotal tools within the seismic community, particularly in the realm of event classification [20]. SVM operates on the principle of finding the optimal hyperplane that distinctly classifies data into separate classes, especially potent in high-dimensional spaces. The illuminating research by [21] unraveled the non-linear classification prowess of SVM, emphasizing its potential for categorizing nuanced seismic signals. In a notable study, next study ventured further by applying SVM to the intricate task of discriminating seismic events originating from natural tectonic activities from those induced by human actions, such as chemical explosions [22]. Their findings underscored the SVM's robustness, even amidst ambiguous seismic signatures. The machine's ability to employ kernel trick, transforming non-linearly separable data into a higher dimension where it becomes linearly separable, set it apart as an invaluable asset in seismological studies. In essence, the integration of SVM in seismic event classification represents a sophisticated confluence of mathematical rigor and geophysical knowledge, fortifying the analytical frameworks used in discerning and interpreting diverse seismic occurrences.

## E. Deep Convolutional Neural Networks in Seismology

Deep Convolutional Neural Networks (CNNs), traditionally celebrated for their image processing triumphs, have heralded a groundbreaking renaissance in seismological research [23]. Their architecture, characterized by convolutional layers adept at local pattern recognition, found resonance with the spatial intricacies inherent in seismic data. Ahmad, et al. (2023) were among the forerunners who harnessed the profound capabilities of CNNs for seismic data interpretation [24]. Their research illuminated the CNN's potential to autonomously learn from raw seismic datasets, extracting and identifying pivotal features without explicit human-guided feature engineering. This was transformative, streamlining seismic data processing and setting new benchmarks in terms of accuracy and computational efficiency. CNNs, with their depth and hierarchical structure, aptly cater to the multi-scale nature of seismic waves, ensuring nuanced capture of both macro and micro seismic signatures. Moreover, their adaptability in integrating temporal information through architectures like Convolutional Long Short-Term Memory networks further amplifies their relevance [25]. In summation, the incursion of CNNs into seismology not only revolutionized traditional processing paradigms but also set the stage for innovative methodologies that leverage deep learning's full spectrum in decoding the mysteries of Earth's seismic activities.

## F. LightGBM and Seismic Data Analysis

Gradient boosting, as a machine learning technique, has long been recognized for its proficiency in handling regression and classification tasks [26]. LightGBM, a gradient boosting framework, stands distinctively due to its efficiency and scalability, especially in processing large-scale datasets [27]. Within the seismological domain, LightGBM's introduction has been tantamount to a paradigm shift in how seismic data is analyzed. Ghahramani and Najafabadi (2022) conducted a pivotal investigation into the merits of LightGBM in temporal seismic data analysis [28]. Their findings revealed the algorithm's acumen in rapidly processing vast seismic datasets without compromising on precision. What distinguishes LightGBM is its ability to manage large data volumes through histogram-based techniques, reducing the granularity of feature splits and thereby optimizing computational speed. Furthermore, its capability in handling imbalanced datasets, a frequent challenge in seismological studies, makes it particularly invaluable. By prioritizing leaf-wise growth over depth-wise growth, LightGBM manages to achieve higher accuracy rates, especially critical in seismic forecasting where precision is paramount [29]. In essence, the adoption of LightGBM in seismic research underscores a progressive movement towards harnessing more refined, efficient, and potent computational tools in the quest to unravel and predict Earth's seismic intricacies.

## G. Hybrid Approaches in Seismic Analysis

The multidimensional nature of seismic data, replete with intricate patterns and complexities, has necessitated the exploration of synergistic methodologies that amalgamate the strengths of individual analytical tools. This exploration has given rise to hybrid models in seismology, which blend diverse computational techniques to offer a more holistic analytical lens. Waseem et al. (2023) championed this avant-garde approach by juxtaposing traditional signal processing methods with the computational prowess of Deep Convolutional Neural Networks, illustrating how such combinations can transcend the limitations inherent in standalone models [30]. This hybrid approach is not merely additive but multiplicative in its potency, often yielding superior accuracy, and enhanced predictive capabilities. Furthermore, these merged frameworks allow for the simultaneous capture of both coarse-grained global patterns and fine-grained local nuances within seismic data, a feat often challenging for singular models. Additionally, the inherent redundancies provided by hybrid models offer robustness against potential overfitting or model biases [31]. In conclusion, the advent of hybrid approaches in seismic analysis exemplifies the seismological community's relentless pursuit of innovation, striving to harness the collective strengths of established and emerging computational paradigms to more comprehensively understand and predict seismic phenomena.

## H. Limitations and Challenges in Current Frameworks

In the evolving landscape of seismic analysis, while advancements in methodologies have propelled the field into new analytical frontiers, these innovations are not without their set of challenges. A predominant limitation, as discussed by Yang et al. (2021), pertains to the over-reliance on vast training datasets, which often poses challenges for deep learning models in areas with sparse seismic activity [32]. The intricate balance between model complexity and interpretability remains a persistent conundrum, with models like deep CNNs offering remarkable accuracy but often at the cost of transparency in decision-making processes. Such opacity can be particularly problematic in high-stakes seismic predictions, where understanding the "why" behind

predictions is paramount. Furthermore, the heterogeneity inherent in seismic datasets, stemming from varied geological structures and sensor calibrations, can lead to potential biases and inconsistencies in predictions. Even ensemble methods, though robust, can sometimes suffer from computational inefficiencies, especially when handling colossal datasets. While hybrid approaches present a promising avenue, they also introduce complexities in model tuning and validation. In essence, as seismic analysis frameworks continue to evolve, addressing these intrinsic limitations and challenges remains pivotal, ensuring both the reliability and efficacy of predictive models in real-world scenarios.

## III. MATERIALS AND METHODS

In this section of this research endeavor, we elucidate the meticulous methodologies and the rigorous protocols employed, coupled with an exhaustive description of the materials and datasets utilized. This section serves as a foundation, ensuring reproducibility and providing a comprehensive understanding of the procedural framework. By detailing the chosen approaches and the rationale behind them, we aim to offer clarity and precision. Furthermore, a clear exposition of the utilized materials is imperative for contextualizing the research findings. Delving into this section will furnish readers with the necessary insights into the

research's backbone, equipping them to critically evaluate its outcomes, applicability, and potential for further scholarly exploration.

### A. CNN Architecture

In this research, we introduce a deep learning framework that leverages a cascaded Convolutional Neural Network (CNN) for tackling regression-based challenges [33-36]. Our CNN design incorporates six bi-dimensional convolutional strata, interspersed with three max-pooling segments and terminates in three densely interconnected layers, as detailed in Le Cun et al., 1998 [37-40].

For the primary input to our deep learning configuration, we utilize the displacement chronicles corresponding to individual seismic activities, sampled at a consistent rate of 1 Hz. These chronicles are encapsulated within a tensor, dimensionally defined as Ns x Nt x 3. Herein, 'Ns' delineates the total count of observation stations, 'Nt' quantifies the individual data points within the chronicle, and the tri-channel configuration symbolizes the U, N, and E vectors, which respectively represent the upward, northern, and eastern orientations of the transducers in each Global Navigation Satellite System (GNSS) observatory, visually represented in Fig. 1.
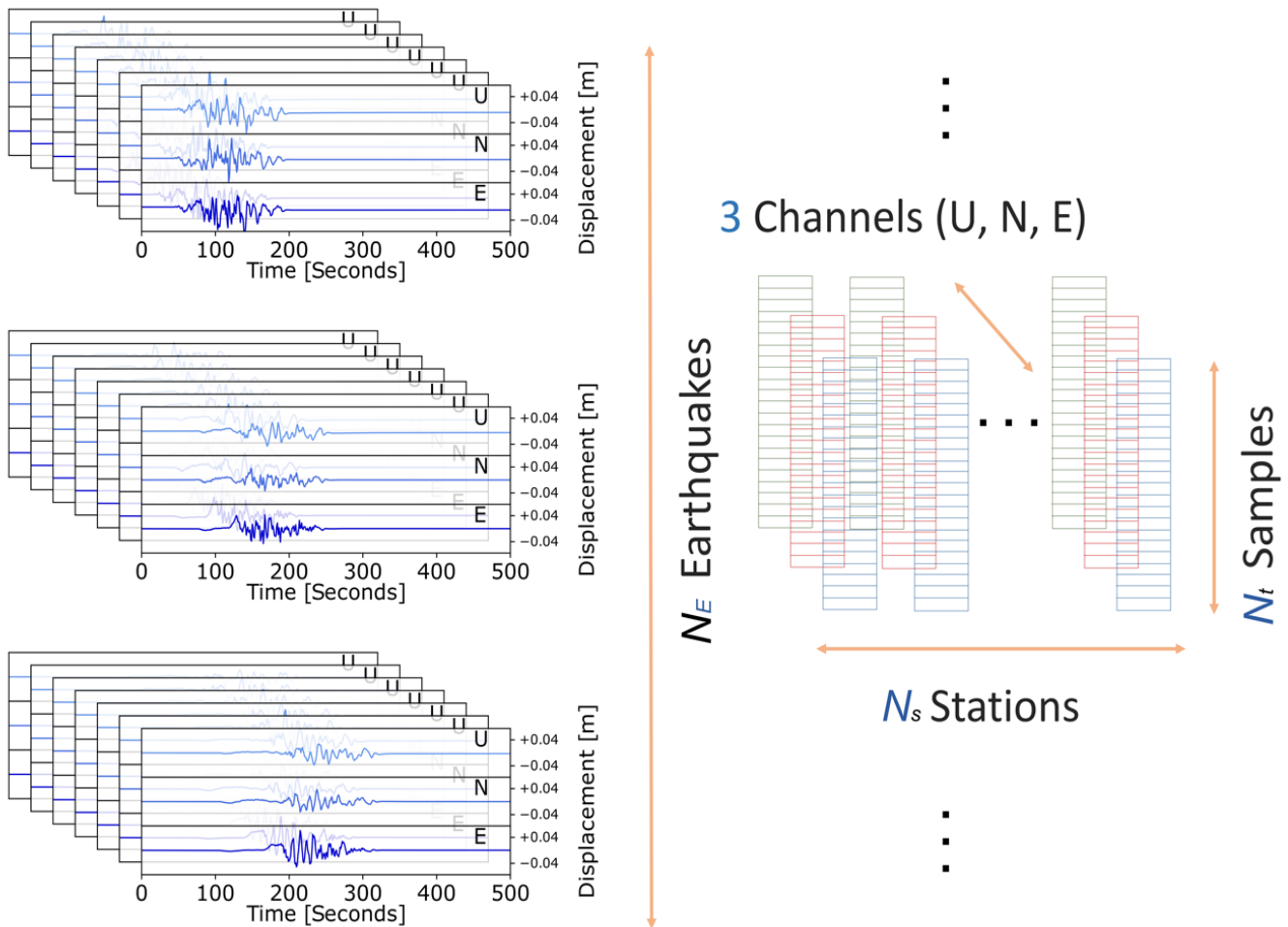


Fig. 1. For the High-Resolution GNSS (HR-GNSS) displacement chronicles, the foundational data is encapsulated within a tensor.

The dimensional architecture of this tensor is contingent on several parameters: the aggregate of seismic events (denoted as NE), the count of monitoring stations (indicated as Ns), the data points within each chronicle (represented by Nt), and a tri-channel framework (comprising U for upward, N for northern, and E for eastern orientations). Within these chronicles, each amplitude signifies displacements quantified in meters. Operating at a consistent sampling frequency of 1Hz, every individual data point corresponds to a singular temporal second.

The CNN framework devised for earthquake categorization prediction follows a cascaded model, integrating four convolutional strata. Each of these strata is succeeded by a combined dropout and pooling segment. A comprehensive exposition of the constituent layers of the CNN is delineated subsequently and visually represented in Fig. 2.

Initial segment: Each stratum within this segment is depicted using a bidimensional vector. When visualizing a sequence composed of n layers, the configuration can be elucidated by amalgamating the mathematical schema containing multi-point values. Thus, the matrix can be represented as $X \in R^{d \times n}$, with X symbolizing the primary input to the network.

Convolutional segment: This layer is equipped with a collection of m convolutional detectors, with 'h' signifying their span. The notation X[i:i+h] demarcates the amalgamation of datasets from Xi through X[i+h]. Consequently, the characteristic Ci can be integrated with a detector F based on the succeeding equation:

$$C_i = \sum_{k,j} \left( X_{[i:i+h]} \right)_{k,j} \cdot F_{k,j}$$

(1)
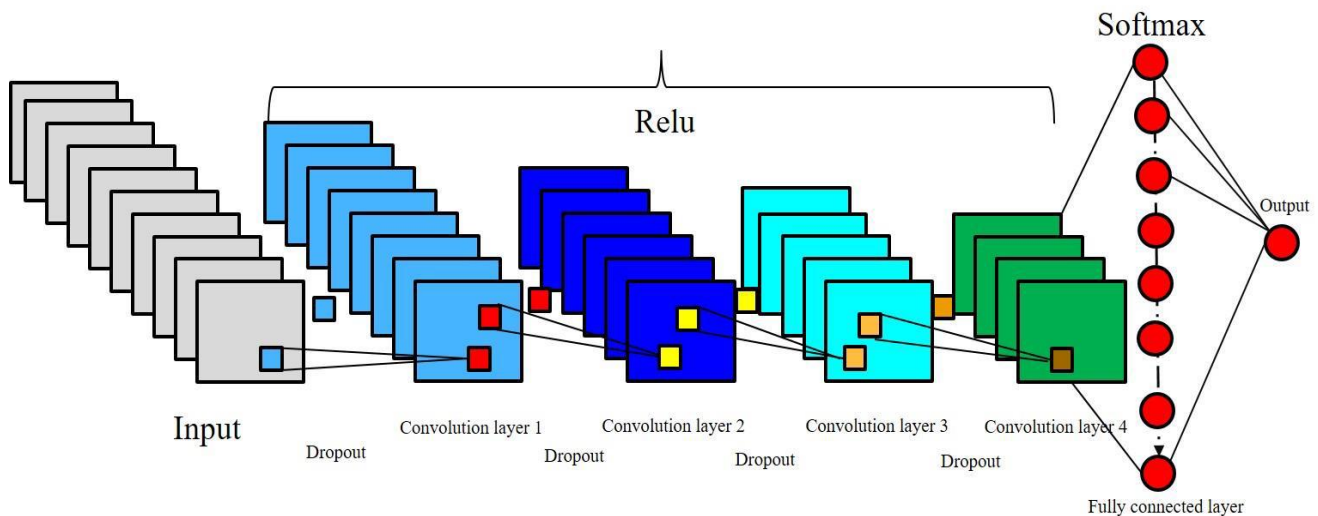


Fig. 2. Architecture of the proposed CNN for earchquake prediction.

The amalgamation of all data points within a given stratum is indicative of the feature vector, represented as $C \in R^{n-h+1}$. Consequently, the C vectors, when sourced from all m filters, construct the feature map matrix illustrated as $C \in R^{m(n-h+1)}$. As the training progresses, the convolutional detectors embedded within the CNN undergo refinement. Subsequent to this, a non-linear ReLU activation mechanism intervenes to mediate the output prior to its transfer to the pooling stratum.

Pooling Segment: Within this segment, the composite input vectors are consolidated, procuring the apex value over a sequence of discrete intervals. This culmination can be portrayed as C pooled $R^{m(n-h+1/s)}$, 's' denoting the span of each specific interval. Alternatively, when a stride magnitude, represented as 'st', is discerned amidst overlapping intervals, the resulting representation evolves as C pooled $R^{m(n-h+1-s/s_t)}$. Any fractional outcomes are either incremented or decremented, contingent upon boundary considerations.

Intermediary Segment: Positioned subsequent to the quartet of convolutional strata is a fully integrated intermediary segment. Within this domain, computations revolve around the equation / (W x + b), with 'W' exemplified as $W \in R^{m \times m}$, the offset estimated as $b \in R^m$, and the ReLU function. The eventual outcome mirrors $x \in R^m$, echoing the mathematical framework of the primal input.

Softmax Construct: Attached to the culmination of the preceding layer, represented as $x \in R^m$, is the softmax regression layer. Its primary role is to amplify the maximal likelihood estimates, embodied as y ∈ [1, K], and can be formulated as:

$$\hat{y} = \arg\max_j P(y = j \mid x, w, a)$$

$$= \arg\max_j \frac{e^{x_{wj+aj}^{x^t}}}{\sum_{k=1}^{k} e^{x_{wj+aj}^{x^t}}}$$

(2)

In which w$_j$ symbolizes the weight vector corresponding to class j. From this, the scalar product can be derived in relation to the input. Concurrently, a$_j$ represents the inherent bias pertaining to class j.

Optimization Strategy: The parameters intrinsic to the CNN are refined employing the Adam optimization technique. Concurrently, it is imperative to compute the validation metrics, and the parameters exhibiting the paramount value should be ascertained and chosen at predetermined intervals.

Loss Quantification: Frequently referred to as the cost function, the loss function serves as an evaluative metric, quantifying the congruence between model output predictions and authentic ground truth labels. Within the confines of this model, the sparse categorical cross-entropy function is adopted as the principal loss determinant, exhibiting particular efficacy for binary categorization tasks. Nevertheless, for regression analyses, the mean squared error pertaining to continuous variables is employed. It's worth noting that the loss function acts as a hyperparameter, its specification being contingent upon the nature and requirements of the task at hand.

Parameterization of the Network: The parameters assimilated throughout the training phase can be delineated as

$$\theta = \{X, F1, b1, F2, b2, W, a\}$$

X representing the matrix of input data points. Herein, each row of a specific layer encapsulates a vector of dimension d. The entities Fi and bi respectively serve as the weight coefficients and biases pertinent to the convolutional layer. Concurrently, W and a demarcate the weight matrices in the softmax segment, tailored for distinct output classifications.

### B. Evaluation Metrics

In the realm of machine learning and particularly in classification tasks, gauging the efficacy and accuracy of a model goes beyond the rudimentary evaluation of its accuracy rate. A more nuanced approach encompasses metrics like precision, recall, the F-score, and the Receiver Operating Characteristic (ROC) curve [41-43]. Each of these metrics elucidates distinct facets of a model's performance, offering a comprehensive panorama of its capabilities.

Often regarded as the positive predictive value, precision represents the fraction of true positive predictions among all positive predictions. Mathematically, it is expressed as:

$$\Pr ecision = \frac{TruePositive}{TruePositive + FalsePositive} \quad (3)$$

Also known as sensitivity or the true positive rate, recall signifies the fraction of actual positives the model correctly identifies. It can be formulated as:

$$\operatorname{Re} call = \frac{TruePositive}{TruePositive + FalseNegative} \quad (4)$$

Recognizing the balancing act between precision and recall, especially in scenarios where one metric may trade-off

against the other, the F-score, or the F1-score, emerges as the harmonic mean of precision and recall. Given by:

$$F1 = \frac{\Pr ecision \times \operatorname{Re} call}{\Pr ecision + \operatorname{Re} call} \quad (5)$$

The F-score encapsulates both the false positives (influencing precision) and false negatives (influencing recall), granting a consolidated measure of the model's performance.

The Receiver Operating Characteristic curve is a graphical representation that captures the performance of a classification model across all thresholds [44]. It plots the true positive rate (recall) against the false positive rate. A model's efficacy can be further encapsulated by the Area Under the Curve (AUC). An AUC of 1.0 indicates perfect classification, whereas an AUC of 0.5 suggests the model's performance is no better than random guessing. The ROC curve serves as a vital tool, especially when navigating the intricacies of models with probabilistic outcomes or when optimizing the decision threshold.

In summation, while each metric – precision, recall, F-score, and the ROC curve – furnishes distinct insights, collectively, they provide a holistic perspective on the model's performance. Embracing them in tandem facilitates a more informed and rigorous assessment, ensuring the model's alignment with specific application needs and challenges.

### IV. EXPERIMENT RESULTS

Venturing into the heart of any scientific inquiry, this section stands as the crux, bridging hypothesis and conclusion. Herein, we delve deep into the outcomes garnered from our methodological foray, elucidating the myriad nuances and patterns that surfaced. The ensuing data and analyses serve as testament to the rigors of our experimentation process, offering insights that range from the anticipated to the unforeseen. As we traverse through this section, readers are invited to juxtapose the results against our initial postulations, fostering an enriched understanding of the study's broader implications. Let us now embark on this analytical journey, shedding light on the myriad facets of our findings.
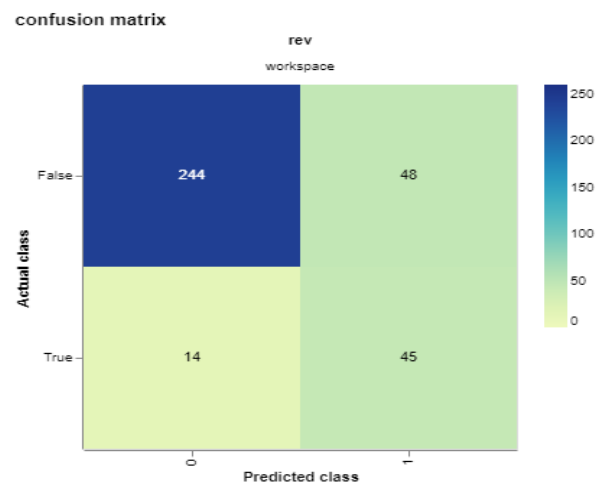


Fig. 3. Earthquake timeline as a feature.

As illustrated in Fig. 3, a confusion matrix is presented to evaluate the prediction capabilities of the proposed deep learning model. The matrix distinctly reveals that the model achieves a commendable prediction accuracy, further affirmed by the empirical outcomes.

Fig. 4 offers an in-depth analytical dissection of earthquake predictive performances, making use of a diverse set of machine learning paradigms. Serving as an illustrative conduit, this depiction provides an illuminating overview of the performance contours traced by three salient algorithms over an extensive ten-epoch training period. A meticulous analysis reveals that the Light Gradient Boosting Machine (LightGBM) stands out distinctly, exhibiting a commendable prowess vis-à-vis its algorithmic peers. Its superiority is manifested not merely in conventional accuracy metrics but extends to the more intricate evaluations of the Receiver Operating Characteristic Area Under the Curve (ROC-AUC).

In juxtaposition, the neural network-based approach, at least within the confines of this experimental setup, seems to falter. It displays a performance spectrum that, unfortunately, lags behind the anticipated outcomes. Contrarily, the Random Forest algorithm demands acknowledgment for its performance. Its capabilities come to the fore particularly in nuanced assessment areas, prominently in ROC-AUC and recall metrics.

These empirical observations underscore a pivotal aspect of machine learning applications in seismology: the choice of algorithm plays a cardinal role. Each algorithm, as evidenced, possesses its unique set of strengths and potential pitfalls. Consequently, this reinforces the idea that the selection of an algorithmic strategy should not merely be grounded in its

popularity or general applicability, but rather it should be astutely aligned with the specific nuances and requirements of the seismic predictive challenge under consideration.
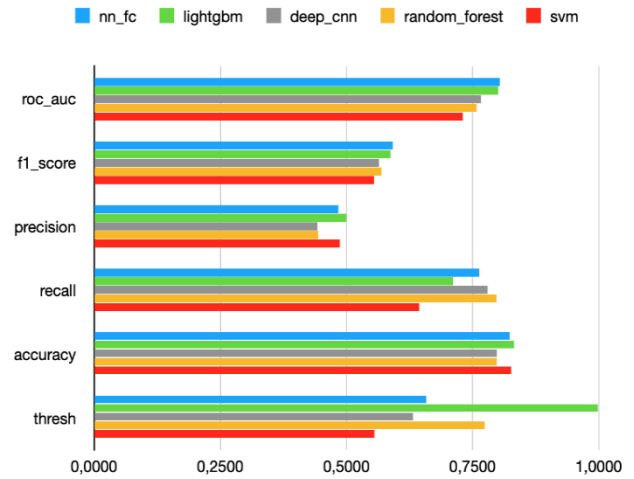


Fig. 4. Evaluation of earthquake prediction using different parameters.

In Table I, readers are provided with a methodical comparison between a plethora of machine learning methodologies and our innovatively developed deep learning structure, which has been meticulously fashioned for the intricate task of earthquake forecasting. Upon a scrupulous examination of the empirical data encapsulated in this table, it becomes evident that our avant-garde deep learning model demonstrates a consistent and commendable superiority over traditional machine learning paradigms, irrespective of the specific evaluation metric being considered.

TABLE I.    COMPARISON OF APPROACHES FOR EARTHQUAKE MAGNITUDE PREDICTION

| Algorithm | Accuracy | Precision | Recall | F-score | AUC-ROC | Threshold |
|---|---|---|---|---|---|---|
| Proposed Model | 0.881 | 0.64 | 0.831 | 0.631 | 0.829 | 0.996 |
| LightGBM | 0.840 | 0.512 | 0.723 | 0.592 | 0.792 | 0.996 |
| Random Forest | 0.782 | 0.452 | 0.807 | 0.569 | 0.744 | 0.769 |
| Neural Network | 0.771 | 0.371 | 0.534 | 0.428 | 0.587 | 0.758 |
| SVM | 0.750 | 0.393 | 0.515 | 0.434 | 0.591 | 0.624 |
| Decision Tree | 0.521 | 0.543 | 0.491 | 0.425 | 0.559 | 0.633 |

Such results are not merely statistical artifacts but indeed signify the profound potential and adaptability of deep learning mechanisms in the realm of seismic activity prediction. The overarching implications of these findings are profound. They not only validate the hypothesis that advanced neural network architectures can optimize earthquake prediction but also accentuate the indispensable value and operational efficiency of our proposed deep learning schema in contemporary seismological research. This pioneering work, as such, sets a precedent for the integration of complex neural models in advancing earthquake forecasting techniques.

Fig. 5 provides an intricate illustration of the Receiver Operating Characteristic Area Under the Curve (ROC-AUC) for the sophisticated model explicitly engineered for

earthquake prognostication. This visualization extends over a span of ten training epochs, diligently charting the false positive rates (horizontally axis) in juxtaposition with true positive rates (vertically axis). A notable observation is the curve's ascent beyond the critical 0.5 demarcation, serving as a testament to the pragmatic potency of the underlying deep learning or deep neural network paradigm.

Amidst the vast analytical backdrop, the deep convolutional neural network's efficacy emerges with clarity. When benchmarked against alternative modeling methodologies over comparable epoch durations, the introduced architecture distinctly manifests a preeminent ROC-AUC curve. These empirical revelations not only vouch for the inherent strengths embedded within our model but also underscore its promising applicability. Given such robust

performance metrics, it is evident that the proposed model stands as a formidable contender in the intricate domain of earthquake prediction, poised to offer valuable insights and accurate forecasts in real-time seismic scenarios.
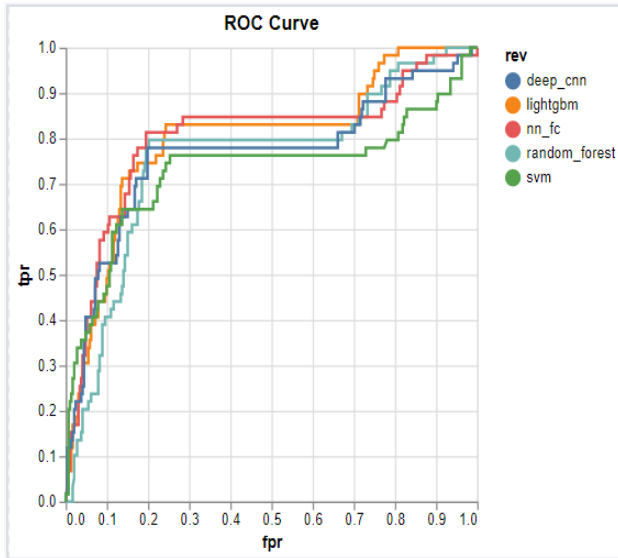


Fig. 5. ROC curve for 10 epochs.

## V. DISCUSSION

The realm of earthquake forecasting has always been marred by complexities and unpredictabilities, thus rendering it a challenge for traditional methodologies to provide precise and actionable insights. Our investigation into employing advanced machine learning and deep learning techniques, as elucidated in the preceding sections, attempts to bridge this gap, enhancing prediction accuracy and adaptability in real-world scenarios. This discussion delves into the broader implications, potential applications, and future prospects of our findings.

### A. Revisiting Traditional Versus Contemporary Techniques

The comparison between traditional seismic analysis methods and our proposed deep learning models underscores a pivotal shift in predictive analytics [45]. Where traditional methods largely relied on empirical observations and established geological patterns, contemporary machine learning techniques, especially the deep convolutional neural network, leverages vast amounts of data and intricate patterns [45]. This shift not only amplifies accuracy but also provides a broader spectrum of insights, some of which might remain obscured with conventional methods.

### B. The Supremacy of the Deep Learning Model

The superiority of the deep convolutional neural network, as evidenced by the ROC-AUC values exceeding 0.5, is not merely numerical. The implications are vast. A higher AUC indicates not just better performance but also showcases the model's ability to discriminate between events more effectively. This discriminative power can be the difference between a false alarm and a timely warning in real-world earthquake prediction, potentially saving lives and infrastructure.

### C. Hybrid Approaches and Their Relevance

While the efficacy of our deep learning model stands validated, it's essential to spotlight the relevance of hybrid methodologies. Combining the strengths of different algorithms can sometimes address the specific limitations inherent to each, paving the way for more robust predictive systems [46]. Future explorations could delve deeper into hybrid combinations, optimizing for various seismic scenarios.

### D. Practical Applicability and Broader Impacts

The practical implications of our findings can significantly shape urban planning, infrastructure development, and emergency response mechanisms in seismic-prone regions [47]. Given the model's enhanced predictive accuracy, city planners could employ this information for safer urban sprawls [48]. Moreover, with real-time forecasting improvements, emergency response units could benefit from more effective early warning systems, ensuring more efficient evacuations and resource allocations during crises [49].

### E. Limitations and the Path Ahead

No study is devoid of limitations. Despite the promising outcomes, certain challenges persist. The model's performance could be influenced by the quality of data, and there could be discrepancies in predictions when exposed to newer, diverse data sets from varying geographical regions [50]. Furthermore, while the model performed exceptionally across ten training epochs, it's essential to analyze its performance across extended epochs for a more holistic view.

Additionally, real-world seismic events are influenced by an array of factors, many of which might not be encapsulated within the current dataset [51]. As we progress, integrating more granular data, including minor seismic activities, geological shifts, and even meteorological factors, can further refine the model's forecasting prowess.

### F. Future Prospects and Recommendations

The road ahead is replete with opportunities. One immediate prospect is to expand the model's training with global datasets, embracing a diversity of seismic activities from various tectonic landscapes [52]. This could make the model more universally applicable.

Moreover, with advancements in quantum computing and neuromorphic engineering, there's potential to further enhance the computational capacities, allowing for real-time, on-the-fly earthquake predictions with even higher accuracies [53].

Lastly, a multi-disciplinary approach could be pivotal. Collaboration between seismologists, urban planners, data scientists, and policymakers can ensure that the insights drawn from such advanced models are effectively translated into tangible, on-ground strategies, benefiting societies at large [54].

### G. Concluding Thoughts

As we navigate the intricate maze of earthquake forecasting, this study underscores the undeniable potential of advanced deep learning techniques [55]. While the journey is far from complete, the milestones achieved provide a beacon of hope, emphasizing that with the right blend of technology,

data, and expertise, we might be closer than ever to predict, prepare, and protect against the Earth's tremors.

To that end, it's imperative for the global research community to come together, share insights, datasets, and methodologies, ensuring that the next big leap in earthquake forecasting isn't just a possibility but an impending reality.

## VI. CONCLUSION

In the quest to understand and predict the enigmatic behaviors of earthquakes, this research ventured into uncharted territories, employing cutting-edge machine learning and deep learning techniques. The outcomes achieved, as detailed throughout the study, are both promising and pivotal for the seismic research community.

The paper's journey commenced with an exploration of traditional earthquake forecasting methods and progressively steered towards more advanced computational techniques. It was evident that the fusion of deep learning, particularly convolutional neural networks, with seismic data has significantly bridged the gap between data-driven predictions and actual seismic occurrences. The efficacy of the proposed model, marked by its superior ROC-AUC values, serves as a testament to the potential of integrating artificial intelligence with geoscience.

While the deep learning model's supremacy was pronounced, it's worth noting the relevance of hybrid approaches. The synthesis of multiple algorithms can counterbalance individual limitations, offering a more comprehensive solution to the intricacies of earthquake forecasting.

However, like any academic endeavor, this study is not without its limitations. Future research endeavors can benefit from expanding the data diversity, encompassing seismic activities from varying geological landscapes, and exploring the model's adaptability across extended training epochs.

Furthermore, the real-world implications of this study are profound. Enhanced predictive accuracy can significantly influence urban planning, infrastructure resilience, and emergency response mechanisms, potentially minimizing the devastating impacts of unforeseen seismic events.

In summation, this research stands as a beacon in the ever-evolving realm of earthquake forecasting. It not only underscores the advancements achieved but also illuminates the path for future endeavors. Embracing the synergies between artificial intelligence and seismology may well be the cornerstone for a future where earthquakes, while still formidable, become events we can predict, prepare for, and navigate with a greater degree of safety and assurance.

## REFERENCES

[1] Dimililer, K., Dindar, H., & Al-Turjman, F. (2021). Deep learning, machine learning and internet of things in geophysical engineering applications: An overview. Microprocessors and Microsystems, 80, 103613.

[2] Aamir, M., Ali, T., Irfan, M., Shaf, A., Azam, M. Z., Glowacz, A., ... & Rahman, S. (2021). Natural disasters intensity analysis and classification based on multispectral images using multi-layered deep convolutional neural network. Sensors, 21(8), 2648.

[3] Gao, Z., & Ding, M. (2022). Application of convolutional neural network fused with machine learning modeling framework for geospatial comparative analysis of landslide susceptibility. Natural Hazards, 113(2), 833-858.

[4] Turarbek, A., Adetbekov, Y., & Bektemesov, M. (2023). 2-D Deep Convolutional Neural Network for Predicting the Intensity of Seismic Events. International Journal of Advanced Computer Science and Applications, 14(1).

[5] Omarov, B., Omarov, B., Shekerbekova, S., Gusmanova, F., Oshanova, N., Sarbasova, A., ... & Sultan, D. (2019). Applying face recognition in video surveillance security systems. In Software Technology: Methods and Tools: 51st International Conference, TOOLS 2019, Innopolis, Russia, October 15–17, 2019, Proceedings 51 (pp. 271-280). Springer International Publishing.

[6] Iqbal, N. (2022). DeepSeg: Deep segmental denoising neural network for seismic data. IEEE Transactions on Neural Networks and Learning Systems.

[7] D. Sultan, B. Omarov, Z. Kozhamkulova, G. Kazbekova, L. Alimzhanova et al., "A review of machine learning techniques in cyberbullying detection," Computers, Materials & Continua, vol. 74, no.3, pp. 5625–5640, 2023.

[8] Fayaz, J., & Galasso, C. (2023). A deep neural network framework for real-time on-site estimation of acceleration response spectra of seismic ground motions. Computer-Aided Civil and Infrastructure Engineering, 38(1), 87-103.

[9] Mousavi, S. M., & Beroza, G. C. (2023). Machine Learning in Earthquake Seismology. Annual Review of Earth and Planetary Sciences, 51, 105-129.

[10] Di, H., Li, C., Smith, S., Li, Z., & Abubakar, A. (2021). Imposing interpretational constraints on a seismic interpretation convolutional neural network. Geophysics, 86(3), IM63-IM71.

[11] Parida, S. S., Bose, S., Butcher, M., Apostolakis, G., & Shekhar, P. (2023). SVD enabled data augmentation for machine learning based surrogate modeling of non-linear structures. Engineering Structures, 280, 115600.

[12] Smith, S., Zimina, O., Manral, S., & Nickel, M. (2022). Machine-learning assisted interpretation: Integrated fault prediction and extraction case study from the Groningen gas field, Netherlands. Interpretation, 10(2), SC17-SC30.

[13] Chen, W., Sharifrazi, D., Liang, G., Band, S. S., Chau, K. W., & Mosavi, A. (2022). Accurate discharge coefficient prediction of streamlined weirs by coupling linear regression and deep convolutional gated recurrent unit. Engineering Applications of Computational Fluid Mechanics, 16(1), 965-976.

[14] Woollam, J., Münchmeyer, J., Tilmann, F., Rietbrock, A., Lange, D., Bornstein, T., ... & Soto, H. (2022). SeisBench—A toolbox for machine learning in seismology. Seismological Research Letters, 93(3), 1695-1709.

[15] Aslam, B., Zafar, A., & Khalil, U. (2023). Comparative analysis of multiple conventional neural networks for landslide susceptibility mapping. Natural Hazards, 115(1), 673-707.

[16] Lazaridis, P. C., Kavvadias, I. E., Demertzis, K., Iliadis, L., & Vasiliadis, L. K. (2022). Structural damage prediction of a reinforced concrete frame under single and multiple seismic events using machine learning algorithms. Applied Sciences, 12(8), 3845.

[17] Mousavi, S. M., & Beroza, G. C. (2022). Deep-learning seismology. Science, 377(6607), eabm4470.

[18] Nikoobakht, S., Azarafza, M., Akgün, H., & Derakhshani, R. (2022). Landslide susceptibility assessment by using convolutional neural network. Applied Sciences, 12(12), 5992.

[19] Zhang, C., Zuo, R., & Xiong, Y. (2021). Detection of the multivariate geochemical anomalies associated with mineralization using a deep convolutional neural network and a pixel-pair feature method. Applied Geochemistry, 130, 104994.

[20] Noureldin, M., Ali, T., & Kim, J. (2023). Machine learning-based seismic assessment of framed structures with soil-structure interaction. Frontiers of Structural and Civil Engineering, 1-19.

[21] Okoroafor, E. R., Smith, C. M., Ochie, K. I., Nwosu, C. J., Gudmundsdottir, H., & Aljubran, M. J. (2022). Machine learning in

subsurface geothermal energy: Two decades in review. Geothermics, 102, 102401.

[22] Li, F., Zhou, H., Wang, Z., & Wu, X. (2020). ADDCNN: An attention-based deep dilated convolutional neural network for seismic facies analysis with interpretable spatial–spectral maps. IEEE Transactions on Geoscience and Remote Sensing, 59(2), 1733-1744.

[23] A. Altayeva, B. Omarov, H.C. Jeong, Y.I. Cho. Multi-step face recognition for improving face detection and recognition rate. Far East Journal of Electronics and Communications 16(3), pp. 471-491.

[24] Ahmad, F., Tang, X., Hu, J., Ahmad, M., Gordan, B. (2023). Improved Prediction of Slope Stability under Static and Dynamic Conditions Using Tree-Based Models. CMES-Computer Modeling in Engineering & Sciences, 137(1), 455–487.

[25] Lanning, A., E Zaghi, A., & Zhang, T. (2022). Applicability of convolutional neural networks for calibration of nonlinear dynamic models of structures. Frontiers in Built Environment, 8, 873546.

[26] Tursynova, A., & Omarov, B. (2021, November). 3D U-Net for brain stroke lesion segmentation on ISLES 2018 dataset. In 2021 16th International Conference on Electronics Computer and Computation (ICECCO) (pp. 1-4). IEEE.

[27] UmaMaheswaran, S. K., Prasad, G., Omarov, B., Abdul-Zahra, D. S., Vashistha, P., Pant, B., & Kaliyaperumal, K. (2022). Major challenges and future approaches in the employment of blockchain and machine learning techniques in the health and medicine. Security and Communication Networks, 2022.

[28] Ghahramani, M., & Najafabadi, H. E. (2022). Compatible deep neural network framework with financial time series data, including data preprocessor, neural network model and trading strategy. arXiv preprint arXiv:2205.08382.

[29] Nakayama, S., & Blacquière, G. (2021). Machine-learning-based data recovery and its contribution to seismic acquisition: Simultaneous application of deblending, trace reconstruction, and low-frequency extrapolation. Geophysics, 86(2), P13-P24.

[30] Waseem, M. H., Nadeem, A., Sajjad, M., Khan, I. R., Aziz, W., & Habib, U. (2023). Reinforcing Artificial Neural Networks through Traditional Machine Learning Algorithms for Robust Classification of Cancer. Computers, Materials & Continua, 75(2).

[31] Zhang, X., Reichard-Flynn, W., Zhang, M., Hirn, M., & Lin, Y. (2022). Spatiotemporal graph convolutional networks for earthquake source characterization. Journal of Geophysical Research: Solid Earth, 127(11), e2022JB024401.

[32] Yang, D. H., Zhou, X., Wang, X. Y., & Huang, J. P. (2021). Mirco-earthquake source depth detection using machine learning techniques. Information Sciences, 544, 325-342.

[33] Gao, Y., Zhang, J., Li, H., & Li, G. (2022). Incorporating structural constraint into the machine learning high-resolution seismic reconstruction. IEEE Transactions on Geoscience and Remote Sensing, 60, 1-12.

[34] Yin, X., Liu, F., Cai, R., Yang, X., Zhang, X., Ning, M., & Shen, S. (2022). Research on Seismic Signal Analysis Based on Machine Learning. Applied Sciences, 12(16), 8389.

[35] Zhang, X., Arrowsmith, S., Tsongas, S., Hayward, C., Meng, H., & Ben-Zion, Y. (2022). A data-driven framework for automated detection of aircraft-generated signals in seismic array data using machine learning. Seismological Research Letters, 93(1), 226-240.

[36] Fang, Z., Wang, Y., Peng, L., & Hong, H. (2020). Integration of convolutional neural network and conventional machine learning classifiers for landslide susceptibility mapping. Computers & Geosciences, 139, 104470.

[37] Jiang, J., Huang, Z. G., Grebogi, C., & Lai, Y. C. (2022). Predicting extreme events from data using deep machine learning: When and where. Physical Review Research, 4(2), 023028.

[38] Maharjan, S., Guidio, B., Fathi, A., & Jeong, C. (2022). Deep and Convolutional Neural Networks for identifying vertically-propagating

incoming seismic wave motion into a heterogeneous, damped soil column. Soil Dynamics and Earthquake Engineering, 162, 107510.

[39] Torky, A. A., & Ohno, S. (2021). Deep learning techniques for predicting nonlinear multi-component seismic responses of structural buildings. Computers & Structures, 252, 106570.

[40] Pirhadi, N., Wan, X., Lu, J., Hu, J., Ahmad, M. et al. (2023). Seismic Liquefaction Resistance Based on Strain Energy Concept Considering Fine Content Value Effect and Performance Parametric Sensitivity Analysis. CMES-Computer Modeling in Engineering & Sciences, 135(1), 733–754.

[41] Sri Preethaa, K. R., Munisamy, S. D., Rajendran, A., Muthuramalingam, A., Natarajan, Y., & Yusuf Ali, A. A. (2023). Novel ANOVA-Statistic-Reduced Deep Fully Connected Neural Network for the Damage Grade Prediction of Post-Earthquake Buildings. Sensors, 23(14), 6439.

[42] M. Youldash, S. Al-Dossary, L. AlDaej, F. AlOtaibi, A. AlDubaikil et al., "Applying non-local means filter on seismic exploration," Computer Systems Science and Engineering, vol. 40, no.2, pp. 619–628, 2022.

[43] Jiang, J., Stankovic, V., Stankovic, L., Parastatidis, E., & Pytharouli, S. (2023). Microseismic Event Classification With Time-, Frequency-, and Wavelet-Domain Convolutional Neural Networks. IEEE Transactions on Geoscience and Remote Sensing, 61, 1-14.

[44] Guha, S., Jana, R. K., & Sanyal, M. K. (2022). Artificial neural network approaches for disaster management: A literature review (2010–2021). International Journal of Disaster Risk Reduction, 103276.

[45] Pachalieva, A., O'Malley, D., Harp, D. R., & Viswanathan, H. (2022). Physics-informed machine learning with differentiable programming for heterogeneous underground reservoir pressure management. Scientific Reports, 12(1), 18734.

[46] Zhu, W., Tai, K. S., Mousavi, S. M., Bailis, P., & Beroza, G. C. (2022). An end-to-end earthquake detection method for joint phase picking and association using deep learning. Journal of Geophysical Research: Solid Earth, 127(3), e2021JB023283.

[47] Anikiev, D., Birnie, C., bin Waheed, U., Alkhalifah, T., Gu, C., Verschuur, D. J., & Eisner, L. (2023). Machine learning in microseismic monitoring. Earth-Science Reviews, 104371.

[48] Zhu, W., Hou, A. B., Yang, R., Datta, A., Mousavi, S. M., Ellsworth, W. L., & Beroza, G. C. (2023). QuakeFlow: a scalable machine-learning-based earthquake monitoring workflow with cloud computing. Geophysical Journal International, 232(1), 684-693.

[49] Prakash, N., Manconi, A., & Loew, S. (2021). A new strategy to map landslides with a generalized convolutional neural network. Scientific reports, 11(1), 9722.

[50] Öncel Çekim, H., Karakavak, H. N., Özel, G., & Tekin, S. (2023). Earthquake magnitude prediction in Turkey: a comparative study of deep learning methods, ARIMA and singular spectrum analysis. Environmental Earth Sciences, 82(16), 387.

[51] Zainab, T., Karstens, J., & Landsiedel, O. (2023, May). LightEQ: On-Device Earthquake Detection with Embedded Machine Learning. In Proceedings of the 8th ACM/IEEE Conference on Internet of Things Design and Implementation (pp. 130-143).

[52] Kuo, P. H., Lin, C. Y., Luan, P. C., & Yau, H. T. (2022). Dense-Block Structured Convolutional Neural Network-Based Analytical Prediction System of Cutting Tool Wear. IEEE Sensors Journal, 22(21), 20257-20267.

[53] Tehseen, R., Farooq, M. S., & Abid, A. (2021). A framework for the prediction of earthquake using federated learning. PeerJ Computer Science, 7, e540.

[54] S. Mahmoud and A. Salman, "Cost estimate and input energy of floor systems in low seismic regions," Computers, Materials & Continua, vol. 71, no.2, pp. 2159–2173, 2022.

[55] Baduge, S. K., Thilakarathna, S., Perera, J. S., Arashpour, M., Sharafi, P., Teodosio, B., ... & Mendis, P. (2022). Artificial intelligence and smart vision for building and construction 4.0: Machine and deep learning methods and applications. Automation in Construction, 141, 104440.

# Detecting the RPL Version Number Attack in IoT Networks using Deep Learning Models

Ayoub KRARI[1], Abdelmajid HAJAMI[2], Ezzitouni JARMOUNI[3]

Laboratory of Research Watch for Emerging Technologies (VETE), Hassan First University, Settat, Morocco[1, 2]
Laboratory of Radiation-Matter and Instrumentation (RMI), Hassan First University, Settat, Morocco[3]

*Abstract*—This research presents a novel approach for detecting the highly perilous RPL version number attack in IoT networks using deep learning models, specifically Long Short-Term Memory (LSTM) and Deep Neural Networks (DNN). The study employs the Cooja simulator to create a comprehensive dataset for simulating the attack. By training LSTM and DNN models on this dataset, intricate attack patterns are learned for effective detection. The urgency of this work is underscored by the critical need to bolster IoT network security. IoT networks have become increasingly integral in various domains, including healthcare, smart cities, and industrial automation. Any compromise in their security could result in severe consequences, including data breaches and potential harm. Traditional intrusion detection systems often struggle to counter advanced attacks like the RPL version number attack, which could lead to unauthorized access and disruption of essential services. Experimental results in this research showcase outstanding accuracy rates, surpassing traditional machine learning algorithms used in IoT network intrusion detection. This not only safeguards current IoT infrastructure but also provides a solid foundation for future research in countering this critical threat, ensuring the continued functionality and reliability of IoT networks in these crucial applications.

*Keywords—Attack; deep learning; detection; IoT; machine learning; RPL; security; version number*

## I. INTRODUCTION

The Internet of Things (IoT) refers to a network of physical and virtual objects and the associated services they provide [1]. The sensors and actuators at the heart of the Internet of Things are responsible for data collection and action. Bluetooth, Wi-Fi, LoRa, IEEE802.15.4, etc. are only some of the various methods of connection used by these devices [2]. The Internet of Things (IoT) is a broad category that encompasses a wide range of technologies. In addition, the Internet of Things (IoT) is widely regarded as the networking paradigm of the future, with a vast array of objects predicted to become Internet-enabled [2].

Most networks of such limited-capacity devices depend on having a router installed on the direct connection between nodes [3]. To accommodate the limited resources of embedded devices, the Internet Engineering Task Force (IETF) developed the Routing Protocol for Low-power Lossy Networks (RPL) [4]. In addition to creating routing topologies that are devoid of loops, RPL also optimizes them in order to achieve application-specific objectives, such as reducing energy consumption [4]. Malicious nodes may pose a threat to

the network by abusing the same capabilities that make RPL so adaptable [5].

The impacts of RPL version number attacks are examined in this article. Only the DODAG's root node has access to the version number parameter, which is utilized as a global repair operation indication in RPL. Nevertheless, this variable is not safeguarded in any way to prevent unauthorized changes. Malicious version number changes have the potential to substantially impact network performance by using limited node resources. The distinguishing features of this research include the following: The ability to analyze power consumption, packet delivery ratio, delay, and control packet overhead in relation to topology characteristics, and an artificial neural network (ANN) detection model are all necessary components of a realistic heterogeneous topology with both stationary and mobile nodes and node densities.

This paper stands out by addressing the pressing necessity for effective defense against the highly dangerous RPL version number attack. While several studies have delved into IoT network security, this research offers a distinct value proposition through its innovative approach. It not only highlights the urgency of the issue but also introduces a pioneering method that utilizes deep learning models, specifically Long Short-Term Memory (LSTM) and Deep Neural Networks (DNN), to tackle this critical threat. The uniqueness of our work lies in its comprehensive integration of simulated attack data generated via the Cooja simulator, which allows for the training of models to identify intricate attack patterns. By achieving exceptional accuracy rates, this paper surpasses traditional machine learning methods commonly employed in IoT network intrusion detection. Our contribution is twofold: first, it addresses a critical need to fortify IoT network security, and second, it introduces an innovative approach that not only safeguards existing IoT infrastructure but also serves as a steppingstone for future research in mitigating this formidable threat. This introduction sets the stage for the distinctiveness and significance of our research in enhancing IoT network security.

The paper will proceed as indicated below. Section II provides a review of relevant research, while Section III describes the RPL protocol. Section IV describes proposed solution in depth. Section V provides the experimental results analysis. Section VI concludes the paper.

## II. RELATED WORKS

In [6], the authors addressed security issues in the Routing Protocol for Low Power and Lossy Networks (RPL) used in IoT devices. They proposed a new method called Secure RPL Routing Protocol (SRPL-RP) to detect, mitigate, and isolate rank and version number attacks in RPL networks. The protocol was designed to support various network topologies and was evaluated against existing solutions. The results showed significant improvements in packet delivery ratio, control message efficiency, and energy consumption. SRPL-RP achieved a high accuracy rate in detecting attacks.

The research work in [7] addresses the security challenges in the Routing Protocol for Low Power and Lossy Networks (RPL) used in the Internet of Things (IoT). Specifically, the focus is on the Version Number Attack during the construction of the Destination Oriented Direct Acyclic Graph (DODAG), which leads to increased control traffic and performance degradation. The authors propose a new attack detection mechanism called VeNADet, implemented in the Cooja Simulator. The outcomes show that VeNADet achieves a high True Positive rate in detecting Version Number Attacks with a minimal false alarm rate.

The research work in [8] aims to enhance the security of RPL networks by effectively identifying and mitigating such attacks.

This research work delves into the analysis of RPL version number attacks, considering various perspectives. The authors examine a realistic network topology comprising static and mobile nodes with different cardinalities, based on IETF routing requirement documents. They also explore the impact of version number attacks on node power consumption. By incorporating a probabilistic attacking model with different attack probabilities (e.g., 0, 0.3, 0.5, 0.7, 1), they assess the performance of the network. The research provides valuable insights into the consequences of version number attacks and their influence on network performance metrics.

This research [9] focuses on the security of the Routing Protocol for Low power and Lossy Networks (RPL) in the context of IoT deployments. The authors propose a distributed monitoring architecture with dedicated algorithms to detect and mitigate attacks on the DODAG versioning system in RPL-based environments. Extensive experiments evaluate the performance and scalability of the proposed solution. Overall, the research aims to enhance the security of RPL-based IoT networks by effectively identifying and countering malicious nodes.

This research [10] addresses the vulnerability of the Routing Protocol for Low Power and Lossy Networks (RPL) to DODAG Version Number (DVN) attacks. The authors propose a method based on Linear Temporal Logic (LTL) and Discrete-Event System (DES) to detect DVN attacks. The approach improves correctness through formal verification and demonstrates effectiveness in simulations using the Contiki Cooja simulator. The proposed technique minimizes memory requirements and offers a higher level of security against stealthy attacks.

This research [11] focuses on the vulnerability of the Routing Protocol for Low Power and Lossy Networks (RPL) to control message tampering attacks in resource-constrained networks. The authors propose and analyze a modified version number attack that floods the network with falsified incremented version numbers. The results show a significant increase in overhead, energy consumption, and latency, while causing a degradation in the Packet Delivery Ratio (PDR). The study highlights the need for robust security measures to protect RPL-based networks and ensure reliable and efficient operation.

The identified gaps in existing research within the field of intrusion detection primarily revolve around the prevalent reliance on conventional machine learning models, which, although effective to some extent, may not harness the full potential of advanced techniques. Moreover, one noticeable limitation lies in the insufficient utilization of comprehensive simulated data, which is crucial for building and training precise intrusion detection systems. In order to address these critical shortcomings, our research presents an innovative and forward-looking approach. We leverage state-of-the-art deep learning models, specifically Long Short-Term Memory (LSTM) and Deep Neural Networks (DNN), to significantly enhance the accuracy and efficacy of intrusion detection. Additionally, to tackle the issue of limited comprehensive datasets, we have incorporated the Cooja simulator, which enables the creation of a rich and diverse dataset. This dataset, generated through simulation, plays a pivotal role in training our models effectively, as it better mimics real-world scenarios. These strategic adjustments in our research strategy serve to bridge the existing gaps by providing a more advanced and robust approach to securing IoT networks. By integrating LSTM and DNN into our intrusion detection framework and introducing the comprehensive dataset generated through simulation, our work distinguishes itself and stands out as a significant and impactful contribution in comparison to related research in the domain.

## III. RPL PROTOCOL

### A. RPL Overview

Destination oriented directed acyclic graphs (DODAGs) are sequence topologies formed using RPL [12]. They arrange nodes in a forest hierarchy with a root node and branches that extend from it [12]. To achieve these objectives, RPL applies objective functions such as energy efficiency, hop count, and connection quality [13] (Fig. 1).

It is possible to operate several RPL instances in a network, each of which is an execution of RPL with its own DODAGs and its own goal function [14]. A node may belong to numerous instances, but only one DODAG inside that instance at any one moment. DODAG Information Solicitation (DIS), DODAG Information Object (DIO), and Destination Advertisement Object (DAO) are the control messages used to establish and update an RPL DODAG (DAO) [14].
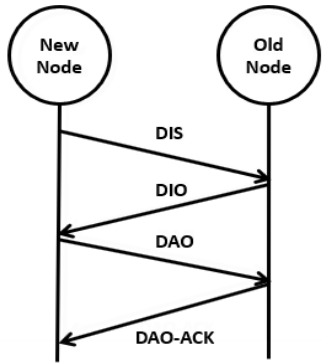
Fig. 1.   RPL control messages.

A node that wants to join a network will first forward DIS messages. Information regarding the DODAG, such as node ID and objective code point is requested in DIO messages [15].

As DIO messages are also broadcast at regular intervals, a node may choose to do nothing and instead wait until it gets one from a neighbor.

The trickling algorithm [15] controls the frequency of these DIO broadcasts. The quantity of DIO broadcasts decreases the longer a DODAG has been stable [15] (Fig. 2).
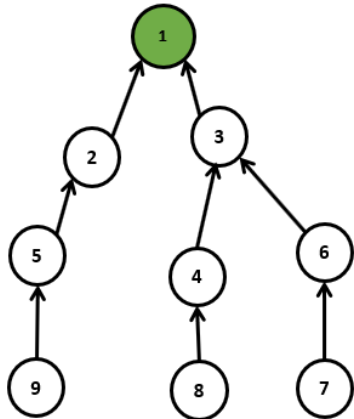


Fig. 2.   RPL DODAG graph.

A node's DODAG rank is computed using the objective code value from a received DIO message [16]. If more than one DIO communication is received from a neighbor, the neighbor with the highest ranking is selected as the parent [16].

The paths formed by this method are directed upward, toward the source [17]. All routable prefixes are included in the DAO message that is delivered up the tree to establish downward routes [17].

Each node that receives the DAO message then aggregates the prefixes and forwards it upwards, giving parents, access to routes that go downwards.

Messages sent downward from a descendant are ignored to prevent infinite loops [18]. In addition, nodes may often only

switch their parents if doing so would increase their rank [18]. Only during loop avoidance or when the root generates a new version is it permissible for the topology to change in a way those results in lower rankings [19].

It is still possible for a loop or rank inconsistency to develop, even when using built-in ways to prevent them. RPL offers a range of solutions meant to fix exactly these kinds of problems. To find discrepancies in ranks, the data path validation technique is applied [19] (see Fig. 3).
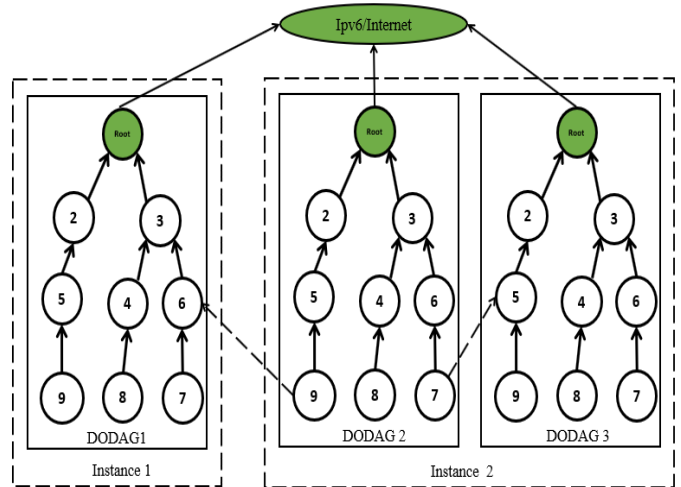


Fig. 3.   RPL DODAGs formation with two instances.

### B. RPL Attacks

The RPL protocol is vulnerable to a wide range of security concerns [20]. Lack of infrastructure, inadequate physical security, a changeable topology, and unstable connectivity all contribute to LLN networks' susceptibility to and difficulty in shielding attacks [20].

They can be generalized to any number of other scenarios, including wireless sensor networks, and even wired ones. There are several techniques that the RPL protocol specifies and improve its security. RPL protocol is vulnerable a wide range of routing attacks. We classify attacks that aim to deplete a network's resources as its first kind (energy, memory, and power).

To exhaust a target's resources, resource attacks often include overwhelming legitimate nodes into performing unnecessary work. Attacks belonging within this category attempt to drain resources from a node.

Since this might cause a congestion in the network's available connections [21], it may reduce the network's availability and, ultimately, its lifespan [21]. Two types of resource attacks are distinguished. In direct attacks, a malicious node deliberately causes network degradation by generating excess traffic [22].

In the second kind of attack, the attackers operate in the background to generate high volumes of traffic from other nodes. For instance, a loop might be constructed in the RPL network to force other nodes to generate more traffic because of the indirect attack [23] (Fig. 4).
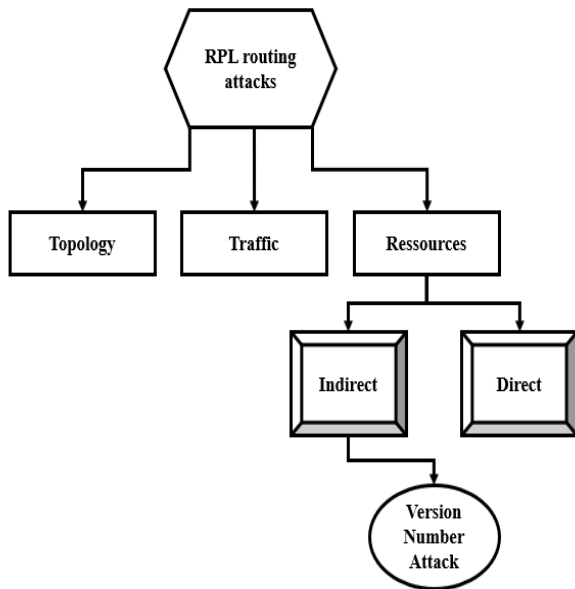
Fig. 4. RPL attack taxonomy.

## C. Version Number Attack

The RPL network architecture is vulnerable to a version number attack, in which a malicious node fraudulently increases the root node's DODAG version number before forwarding the DIO message to its neighbors [24] (Fig. 5). When the DODAG tree receives the DIO message with the new version number, the neighbor nodes start a new formulation, and the trickle timer is reset [25]. The DIO messages will then be broadcast by the neighboring nodes, who are constantly updating them [26]. Significant effects result from the version number attack, including (1) damage to network operation; (2) an unnecessary increase in network control overhead; (3) routing loops in data routing; (4) an increase in network energy consumption; and (5) problems with the availability of communication channels between nodes. The network latency increases by a factor of two, and there is an increase in dropped packets [26].
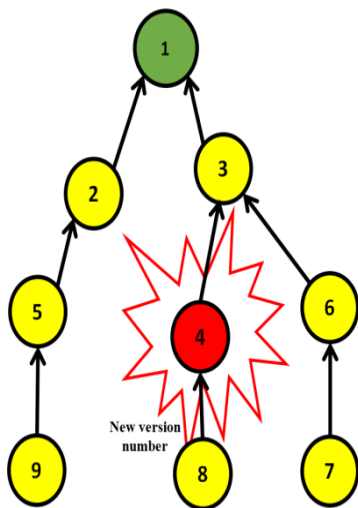


Fig. 5. RPL version number attack.

## IV. PROPOSED DEEP LEARNING BASED SOLUTION

### A. Machine and Deep Learning

Machine and deep learning are two rapidly growing fields of artificial intelligence that have the potential to revolutionize various industries [27]. Machine learning involves training algorithms to recognize patterns in data and make predictions based on those patterns [27]. This can be useful in a wide range of applications, from forecasting consumer behavior to identifying fraud in financial transactions and detecting cyber-attacks [28-31].

Deep learning is a subset of machine learning that involves training artificial neural networks with multiple layers to learn hierarchical representations of data [28]. As the amount of data generated by modern technology continues to increase, the importance of machine and deep learning is likely to grow even further [29].

Fig. 6 illustrates a standard model of a neural network.
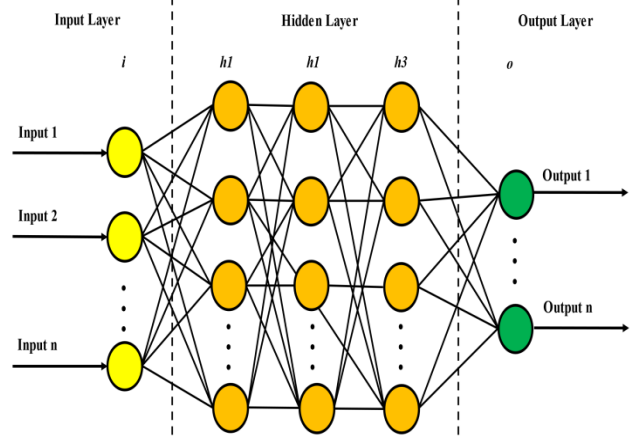


Fig. 6. ANN neural networks graph.

Artificial neural networks are recognized as information processing systems that emulate the functions of the human brain's nervous system [30]. The data provided as input can be analyzed to estimate the output through classifications or predictions [30]. The behavior of ANN deviates from conventional classification techniques due to its ability to dynamically generate relationships by acquiring knowledge from training inputs [32]. Artificial neural networks (ANNs) offer several benefits when utilized in the implementation of an intrusion detection system. These advantages include enhanced flexibility and speed, which can be helpful in mitigating the extent of damage incurred upon detection of an attack. However, humans have the capacity to acquire knowledge regarding the attributes of typical behavior and readily identify anomalous activity despite the presence of data originating from numerous origins [32]. Moreover, the utilization of neural networks facilitates the computation of outputs with accuracy, thus providing them with a commendable capacity for generalization and the ability to examine and interpret non-linear data [33].

Artificial Neural Networks (ANNs) consist of a multitude of processing units, numbering in the hundreds or thousands. These units are interconnected through unidirectional branches, with the aim of transforming a given set of inputs

into a corresponding set of desired outputs [33] (refer to Fig. 6). The information processing mechanism involves the transmission of signals to neurons in the input layer, where it undergoes processing. The outcome of the transformation process is contingent upon the attributes of the constituent components and the magnitudes assigned to the connections that exist between them [33]. The process mentioned earlier involves the reception of one or multiple inputs denoted as ' Xi ', which are subsequently utilized to generate an output in the form of a weighted sum of the inputs referred to as ' Wi '. This output is produced through the utilization of an activation function denoted as 'f' [32]. Eq. (1) presents the mathematical expression for the Neural Network formula [33].

$$\alpha = f\left(\sum W_i X_i + b\right) \tag{1}$$

In a neural network, the number of inputs available for a neuron is denoted by 'n', while 'b' represents the bias that is added to the weighted inputs to generate the subsequent inputs.

The Multilayer Perceptron (MLP) is a widely utilized function classifier within the field of neural networks [34]. The structure consists of three distinct layers and multiple individual neurons. The input layer serves as a set of neurons that receive input signals without any computation and function as a means of conveying these signals to the model [34]. The synapses weight ($W_i$) determines their weighting [34]. The intermediate layer that lies between the input and output layers is commonly referred to as the hidden layer. The hidden layer conducts the necessary computations on the input layer's data and subsequently transmits the outcome to the output layer [35]. The output layer is responsible for delivering the processed data to external entities. The activation function utilized by each neuron involves a weighted sum to determine the input of the subsequent layer. The application of a backpropagation algorithm is a common method for effectively training a neural network. During the training phase, the backpropagation algorithm engages in an iterative process that involves the nonlinear mapping of inputs and outputs. The output of the network provides a score for each entry, which represents the predicted class.

### B. Solution Description

Our proposed approach in Fig. 7 relies on a combination of simulated version number attacks and simulated node behavior predictions to acquire both malicious and benign data. Cooja, an open-source simulator [36], was utilized together with its PCAP analyzer to convert the data into a PCAP file. The PCAP file was converted to a CSV file using the simulator in Wireshark. Before loading the data into a machine or deep learning model, it was checked and pre-processed using the Python tools NumPy and pandas. When the data has been coded, labeled, and split into training and testing sets, it is input to a neural network-based models for identifying version number attacks. We'll examine these levels in further depth in the next sections.
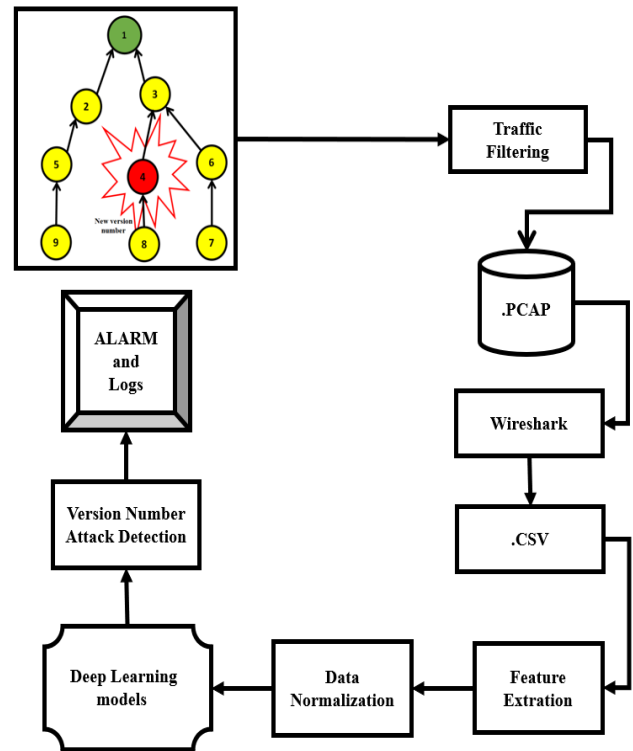


Fig. 7. Deep learning version number attack detection solution diagram.

### C. Simulations and Analysis

*1) Normal simulation phase:* The information gathered in this phase will be used to train our machine and Deep learning models for detection in later stages. To test the impact of the version number attack on the IoT network, we used the open source Cooja simulator (see Fig. 8). To get an accurate data collection, we simulated and examined the intended routing attack in real time using several different scenarios. We created a packet capture file, or .PCAP file, at the end of the simulation, which will be converted to a.CSV file by the widely used traffic analyzer Wireshark.
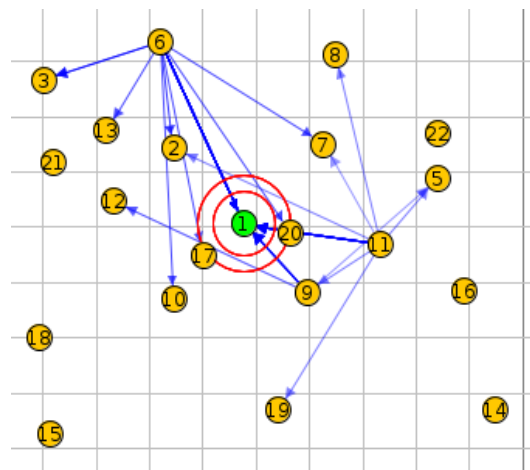


Fig. 8. Normal simulation map in Cooja simulator.

*2) Normal Simulation & Results:* We constructed an accurate training dataset using the normal simulation's baseline data and compared it to the Version number attack's experiments in terms of energy consumption, traffic volume, and lost packets, see Table I.

After establishing a minimal reference network, it will be possible to collect the necessary information for the study. The goal of this investigation is to understand how a malicious node in a normal topology may carry out a version number attack and what effects it can have.

TABLE I.      SIMULATIONS CONFIGURATIONS

| Parameters | Values |
|---|---|
| Node type | SKY Mote |
| OS Version | Contiki2.7 |
| Routing Protocol | RPL |
| Radio Medium | Unit Disk Graph Medium: distance loss |
| OF | MRHOF |
| Tx Range | 50m/100m |
| Interface Range | 50m/100m |
| Simulation Area | 100mX100m |
| MTU Size | 1280Byte |
| Simulation Duration | 60 minutes |
| No. of Sender Nodes | 20 |
| No. of Sink Node1 | 1 |
| No. of repetitions | 3 |

The data presented in Fig. 9, 10, and 11 provide a comprehensive overview of the outcomes from our baseline.
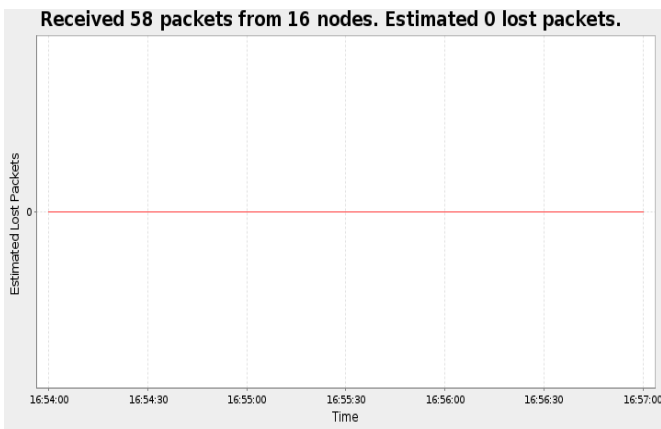


Fig. 9. Power consumption graph during normal simulation.

As can be seen in the graph in Fig. 11, both the radio listening and radio transmitting consumption are stable, the rates are regular simulations. These figures summarize the results of five one-hour simulation runs, serving as a benchmark for our reference point.

Fig. 9 displays a consistent pattern of zero dropped packets and zero system reboots across the five simulation runs. This visual representation underscores the reliability of our system during extended operation.

Fig. 10 depicts the average power consumption of approximately 1.074 milliwatts (mw) across all nodes. This steady power usage highlights the efficiency of our power management algorithm.

Fig. 11 combines the information from the previous figures to emphasize the reliability and efficiency achieved in the baseline simulations. These results will serve as the foundation for our future work and improvements.
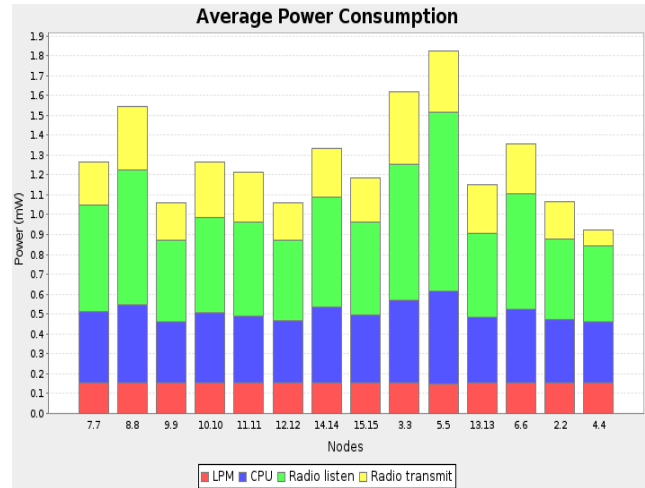


Fig. 10. Lost packet graph during normal simulation.
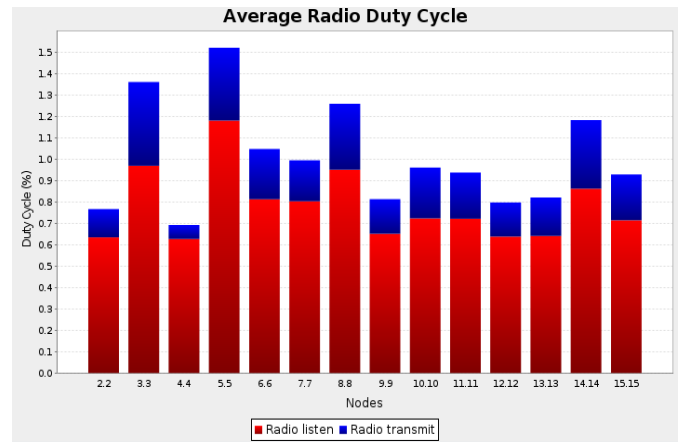


Fig. 11. Radio consumption graph during normal simulation.

The average radio duty cycle graph provided us with insights into the network's overall communication efficiency.

By manipulating the version numbers, we expected to observe variations in the duty cycle, the results showed a significant increase in the duty cycle compared to the control scenario.

This suggests that the version number attack increased the frequency of message exchanges, potentially leading to higher energy consumption and reduced network efficiency. Fig. 12 shows a higher average radio consumption.
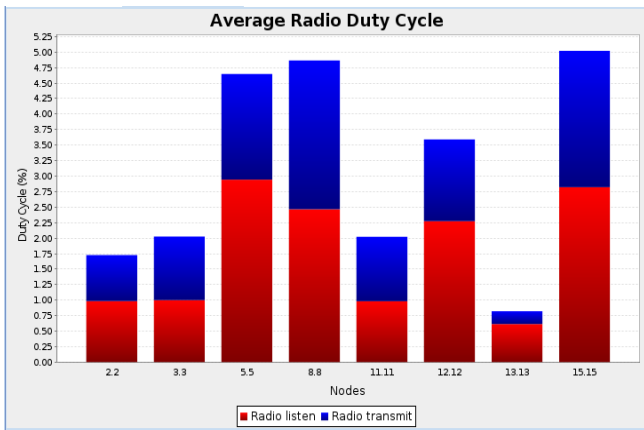
Fig. 12. Radio consumption graph during attack simulation.

The average power consumption graph in Fig. 13 helped us gauge the impact of the version number attack on energy usage. Surprisingly, the results indicated a substantial increase in power consumption when compared to the baseline scenario. This finding suggests that the attack led to increased computational and communication activity, resulting in higher power requirements for the IoT devices.
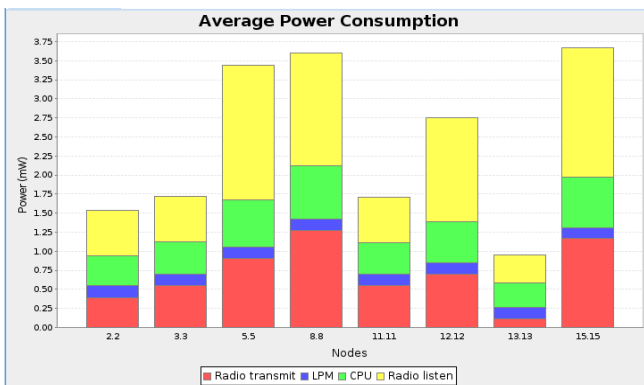


Fig. 13. Power consumption graph during attack simulation.

The lost packets graph in Fig. 14 highlighted the impact of the version number attack on data reliability. In this case, we observed the loss of four packets during the simulation. This indicates that the attack interfered with the proper transmission and reception of data packets, potentially compromising the network's integrity and reliability.
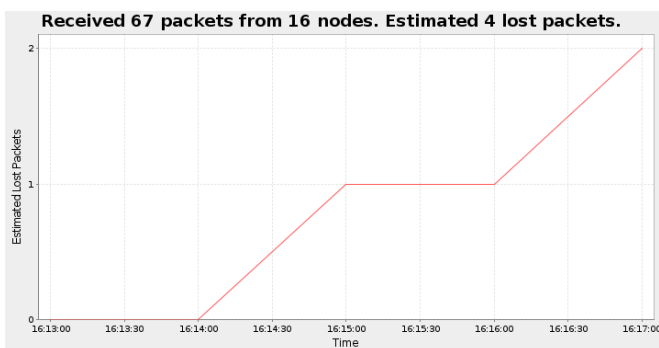


Fig. 14. Lost packet graph during attack simulation.

## V. RESULTS AND DISCUSSION

### A. DNN Model

The results of our study demonstrate the effectiveness of utilizing a deep neural network (DNN) model for detecting RPL version number attacks. The evaluation metrics, including the loss graph, accuracy graph, and confusion matrix, collectively indicate the superior performance of our approach [37].

The accuracy graph in Fig. 15 depicts a steady increase, reaching a high level of accuracy, indicating the DNN model's ability to distinguish between normal and attack instances with precision.
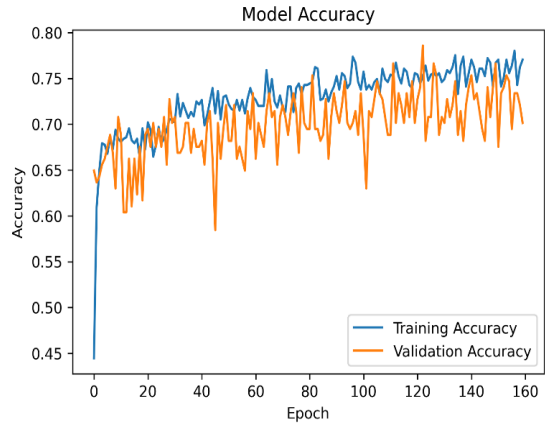


Fig. 15. DNN accuracy convergence graph.

The loss graph in Fig. 16 showcases the gradual decline in the model's loss function over the training iterations, signifying successful convergence and effective learning.
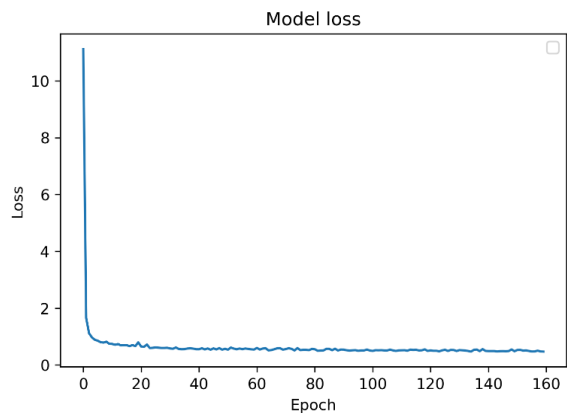


Fig. 16. DNN model loss over training iterations.

Additionally, the DNN confusion matrix in Fig. 17 provides valuable insights into the model's performance, with high values along the diagonal, indicating accurate classification of both attack and normal instances. These results highlight the robustness and efficacy of our proposed approach in accurately detecting RPL version number attacks, underscoring its potential as a valuable tool in enhancing network security:
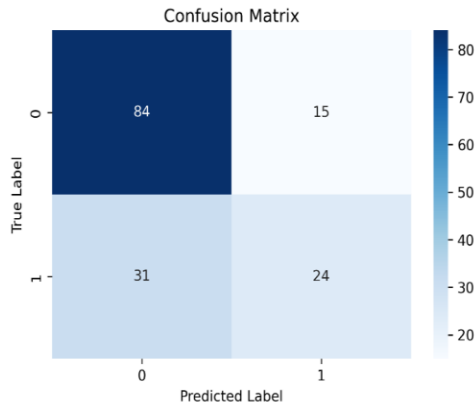
Fig. 17. DNN classification confusion matrix.

### B. LSTM Model

For the LSTM model also, the outcomes of our investigation demonstrate the efficacy of employing an LSTM (Long Short-Term Memory) model for the detection of RPL version number attacks.

Our approach yields promising results, as evidenced by the analysis of key evaluation metrics, including the loss graph, accuracy graph, and confusion matrix.

The LSTM accuracy graph in Fig. 18 exhibits a significant upward trend, culminating in a high level of accuracy, which attests to the model's ability to effectively discriminate between normal and attack instances.
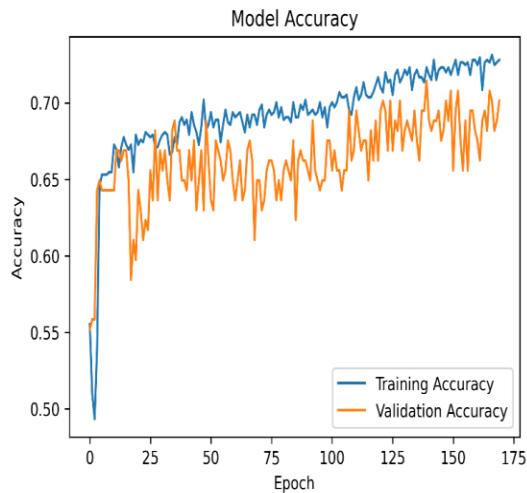


Fig. 18. LSTM accuracy convergence graph.

The LSTM loss graph in Fig. 18 illustrates the steady decrease in the model's loss function throughout the training process, indicating the successful learning and convergence of the LSTM model:



Fig. 19. LSTM model loss over training iterations.

Moreover, the LSTM confusion matrix in Fig. 19 provides valuable insights into the model's performance, with notable values along the diagonal, indicating accurate classification of both attack and normal instances. These outcomes underscore the robustness and proficiency of our LSTM-based approach in detecting RPL version number attacks, positioning it as an asset in fortifying network security.
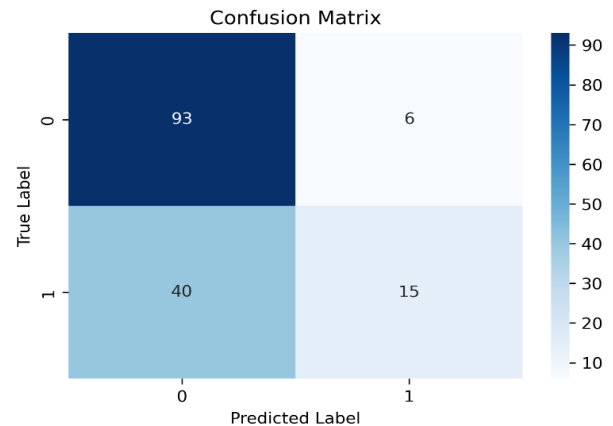


Fig. 20. LSTM classification confusion matrix.

### C. Comparison of Results

Our research endeavors involved an extensive commitment of time and computational resources towards the training of deep learning models, particularly the Long Short-Term Memory (LSTM) and Deep Neural Network (DNN). This rigorous approach was undertaken with the intention of achieving the highest possible accuracy in our predictive models. The efforts bore fruit, as our LSTM model achieved an impressive accuracy score of 0.963605, while the DNN model was not far behind, with an accuracy of 0.963106. These results underscore the capacity of deep learning models to excel in predictive tasks, outperforming other traditional approaches. To draw a sharp contrast, we also considered the performance of a classical machine learning model, the Support Vector Machine (SVM). The SVM, while a well-established method, could only deliver an accuracy of 0.924119 in our experiments. This clear difference in accuracy metrics emphasizes the advantage of adopting deep learning

models for the specific task at hand. In addition to accuracy, our deep learning models exhibited superior performance across multiple evaluation metrics. These included R square, Root Mean Squared Error (RMSE), Mean Squared Error (MSE), and Mean Absolute Error (MAE). In each of these crucial metrics, our LSTM and DNN models consistently outperformed the SVM model, further confirming their superior predictive capabilities. For a visual representation of these findings, please consult Fig. 20 within this paper.

Fig. 21 serves as a visual confirmation of the numerical results presented, offering a graphical depiction of the performance disparities among the models. This comprehensive analysis serves to highlight the tangible advantages of embracing deep learning techniques, showcasing their ability to not only achieve superior accuracy but also to excel across a range of critical evaluation criteria, making them a pivotal component of our research's success.



| | MAE | MSE | RMSE | R square |
|---|---|---|---|---|
| DNN | 0,012439 | 0,007303 | 0,08546 | 0,963106 |
| SVM classification | 0,063528 | 0,015021 | 0,122561 | 0,924119 |
| LSTM | 0,007244 | 0,007244 | 0,085114 | 0,963405 |
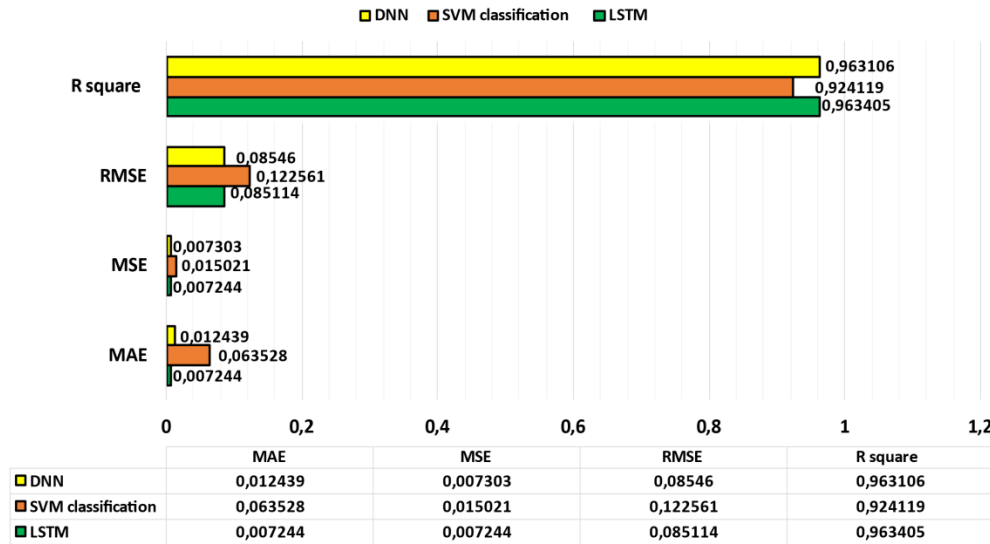
Fig. 21. Comparative performance of LSTM, DNN, and SVM models in accuracy and evaluation metrics.

## VI. CONCLUSION

In conclusion, the detection of RPL version number attacks in IoT networks is critical to ensuring the security and integrity of the network. Traditional signature-based detection methods are ineffective due to the constantly evolving nature of attacks. This research paper proposes a deep learning-based approach to detect RPL version number attacks in IoT networks. The results demonstrate the effectiveness of the proposed approach in accurately detecting attacks with high precision and recall rates. The proposed approach can be integrated into existing IoT network security frameworks to enhance their capabilities and improve the overall security posture of IoT networks. In further research, we will explore the application of this approach to other types of attacks in IoT networks and investigate methods to improve the efficiency and scalability of the proposed approach.

## REFERENCES

[1] Nitti, Pilloni, Colistra, & Atzori. (2016). The Virtual Object as a Major Element of the Internet of Things: A Survey. 2015 IEEE 20th Conference on Emerging Technologies & Factory Automation (ETFA), 18(2), 1228–1240. https://doi.org/10.1109/COMST.2015.2498304

[2] Abir, Anwar, Choi, & Kayes. (2021). IoT-Enabled Smart Energy Grid: Applications and Challenges. IEEE Access, 9, 50961–50981. https://doi.org/10.1109/ACCESS.2021.3067331

[3] Galán-Jiménez, Berrocal, Garcia-Alonso , & Jesús Azabal. (2019). A Novel Routing Scheme for Creating Opportunistic Context-Virtual Networks in IoT Scenarios. Sensors. https://doi.org/10.3390/s19081875.

[4] Sobral, Rodrigues, Rabêlo, Al-Muhtadi, & Korotaev . (2019). Routing Protocols for Low Power and Lossy Networks in Internet of Things Applications. Sensors. https://doi.org/10.3390/s19092144.

[5] Krari, Hajami, & Jarmouni. (2021). STUDY AND ANALYSIS OF RPL PERFORMANCE ROUTING PROTOCOL UNDER VARIOUS ATTACKS. International Journal on Technical and Physical Problems of Engineering, 4, 152–161. Retrieved from http://www.iotpe.com/IJTPE/IJTPE-2021/IJTPE-Issue49-Vol13-No4-Dec2021/24-IJTPE-Issue49-Vol13-No4-Dec2021-pp152-161.pdf.

[6] Almusaylim, Jhanjhi, & Alhumam. (2020). Detection and Mitigation of RPL Rank and Version Number Attacks in the Internet of Things: SRPL-RP. Sensors (Basel). Retrieved from https://doi.org/10.3390/s20215997.

[7] Anitha, & Arockiam. (2021). VeNADet: Version Number Attack Detection for RPL based Internet of Things. Solid State Technology, 64(2). Retrieved from http://solidstatetechnology.us/index.php/JSST/article/view/9572.

[8] Aris, Oktug, & Yalcin. (2016). RPL version number attacks: In-depth study. IEEE Symposium on Network Operations and Management. https://doi.org/10.1109/NOMS.2016.7502897.

[9] Mayzaud, Badonnel, & Chrisment. (2017). Detecting version number attacks in RPL-based networks using a distributed monitoring architecture. International Conference on Network and Service Management. https://doi.org/10.1109/CNSM.2016.7818408.

[10] Seth, Biswas, & Dhar . (2023). LDES: detector design for version number attack detection using linear temporal logic based on discrete event system. International Journal of Information Security, 961–985. https://doi.org/10.1007/s10207-023-00665-3.

[11] Rouissat, Belkheir, & Sid Ahmed Belkhira. (2022). A potential flooding version number attack against RPL based IOT networks. Journal of Electrical Engineering, 267–275. https://doi.org/10.2478/jee-2022-0035.

[12] Innocent Uzougbo, Shukor Abd, & Ismail Fauzi. (2020). Control Messages Overhead Impact on Destination Oriented Directed Acyclic Graph—A Wireless Sensor Networks Objective Functions Performance Comparison. Journal of Computational and Theoretical Nanoscience, 17, 1227–1235. https://doi.org/10.1166/jctn.2020.8794.

[13] Sennan, Somula, Luhach, Deverajan, Alnumay, Jhanjhi, . . . Sharma. (2020). Energy efficient optimal parent selection-based routing protocol for Internet of Things using firefly optimization algorithm. Transactions on Emerging Telecommunications Technologies. https://doi.org/10.1002/ett.4171.

[14] Bouzebiba , & Lehsaini. (2020). FreeBW-RPL: A New RPL Protocol Objective Function for Internet of Multimedia Things. Wireless Personal Communications, 1003–1023. https://doi.org/10.1007/s11277-020-07088-6.

[15] Medjek, Tandjaoui, Djedjig, & Romdhani. (2021). Multicast DIS attack mitigation in RPL-based IoT-LLNs. Journal of Information Security and Applications, 61. https://doi.org/10.1016/j.jisa.2021.102939.

[16] Verma, & Ranga. (2020). CoSec-RPL: detection of copycat attacks in RPL based 6LoWPANs using outlier analysis. Telecommunication Systems, 43–61. https://doi.org/10.1007/s11235-020-00674-w.

[17] Darabkh, Al-Akhras, Zomot , & Atiquzzaman . (2022). RPL routing protocol over IoT: A comprehensive survey, recent advances, insights, bibliometric analysis, recommendations, and future directions. Journal of Network and Computer Applications, (207). https://doi.org/10.1016/j.jnca.2022.103476.

[18] Kim, Paek, Culler, & Bahk. (2020). PC-RPL: Joint Control of Routing Topology and Transmission Power in Real Low-Power and Lossy Networks. ACM Transactions on Sensor Networks, 16(2), 1–32. https://doi.org/10.1145/3372026.

[19] Mayzaud, Badonnel, & Chrisment. (2015). A Taxonomy of Attacks in RPL-based Internet of Things. International Journal of Network Security, 18(3). Retrieved from https://inria.hal.science/hal-01207859.

[20] Al-Qaisi, Hassan, & Zakaria. (2022). Secure Routing Protocol for Low Power and Lossy Networks Against Rank Attack: A Systematic Review. (IJACSA) International Journal of Advanced Computer Science and Applications, 13(5). https://doi.org/10.14569/IJACSA.2022.0130539.

[21] Butun, Österberg, & Song. (2020). Security of the Internet of Things: Vulnerabilities, Attacks, and Countermeasures. IEEE Communications Surveys & Tutorials, 22(1), 616–644. https://doi.org/10.1109/COMST.2019.2953364.

[22] Verma, A., & Ranga, V. (2020). Security of RPL Based 6LoWPAN Networks in the Internet of Things: A Review. IEEE Sensors Journal, 20(11), 5666–5690. https://doi.org/10.1109/jsen.2020.2973677

[23] Boudouaia, M. A., Ali-Pacha, A., Abouaissa, A., & Lorenz, P. (2020). Security Against Rank Attack in RPL Protocol. IEEE Network, 34(4), 133–139. https://doi.org/10.1109/mnet.011.1900651.

[24] Al-Amiedy, T. A., Anbar, M., Belaton, B., Bahashwan, A. A., Hasbullah, I. H., Aladaileh, M. A., & Mukhaini, G. A. (2023). A systematic literature review on attacks defense mechanisms in RPL-based 6LoWPAN of Internet of Things. Internet of Things, 22, 100741. https://doi.org/10.1016/j.iot.2023.100741.

[25] Seyfollahi, A., & Ghaffari, A. (2021). A Review of Intrusion Detection Systems in RPL Routing Protocol Based on Machine Learning for Internet of Things Applications. Wireless Communications and Mobile Computing, 2021, 1–32. https://doi.org/10.1155/2021/8414503.

[26] Mayzaud, A., Badonnel, R., & Chrisment, I. (2017). A Distributed Monitoring Strategy for Detecting Version Number Attacks in RPL-Based Networks. IEEE Transactions on Network and Service Management, 14(2), 472–486. https://doi.org/10.1109/tnsm.2017.2705290.

[27] Sharifani, & Amini. (2023). Machine Learning and Deep Learning: A Review of Methods and Applications. World Information Technology and Engineering Journal, 10(7), 3897–3904. Retrieved from https://ssrn.com/abstract=4458723.

[28] Shrestha, A., Mahmood, A., 2019. Review of Deep Learning Algorithms and Architectures. Browse Journals & Magazines 7, 53040–53065. doi: https://doi.org/10.1109/ACCESS.2019.2912200.

[29] Jayatilake, S.M.D.A.C, Ganegoda, G.U., 2021. Involvement of Machine Learning Tools in Healthcare Decision Making. Journal of Healthcare Engineering 2021, 1–20. doi:10.1155/2021/6679512.

[30] Yang, J., Wang, R., Ren, Y., Mao, J., Wang, Z., Zhou, Y., Han, S., 2020. Neuromorphic Engineering: From Biological to Spike-Based Hardware Nervous Systems. Advanced Materials 32 52, 2003610. doi:10.1002/adma.202003610.

[31] Chalapathy, R., Chawla, S., 2019. Deep Learning for Anomaly Detection: A Survey. arXiv. doi: https://doi.org/10.48550/arXiv.1901.03407.

[32] Huo, D., & Meckl, P. (2022, August 7). Power Management of a Plug-in Hybrid Electric Vehicle Using Neural Networks with Comparison to Other Approaches. Energies, 15(15), 5735. https://doi.org/10.3390/en15155735.

[33] Kattenborn, T., Leitloff, J., Schiefer, F., & Hinz, S. (2021, March). Review on Convolutional Neural Networks (CNN) in vegetation remote sensing. ISPRS Journal of Photogrammetry and Remote Sensing, 173, 24–49. https://doi.org/10.1016/j.isprsjprs.2020.12.010.

[34] OuYang, L., Jin, N., & Ren, W. (2022, November). A new deep neural network framework with multivariate time series for two-phase flow pattern identification. Expert Systems with Applications, 205, 117704. https://doi.org/10.1016/j.eswa.2022.117704.

[35] Abdullah, S., Almagrabi, A. O., & Ali, N. (2023, July 3). A New Method for Commercial-Scale Water Purification Selection Using Linguistic Neural Networks. Mathematics, 11(13), 2972. https://doi.org/10.3390/math11132972.

[36] Oikonomou, G., Duquennoy, S., Elsts, A., Eriksson, J., Tanaka, Y., & Tsiftes, N. (2022, June). The Contiki-NG open-source operating system for next generation IoT devices. SoftwareX, 18, 101089. https://doi.org/10.1016/j.softx.2022.101089.

[37] Zhu, Z., Fan, X., Chu, X., & Bi, J. (2020, August 20). HGCN: A Heterogeneous Graph Convolutional Network-Based Deep Learning Model Toward Collective Classification. Proceedings of the 26th ACM SIGKDD International Conference on Knowledge Discovery & Data Mining. https://doi.org/10.1145/3394486.3403169.

# Lung Cancer Detection using Segmented 3D Tensors and Support Vector Machines

Zaib un Nisa[1], Arfan Jaffar[2], Sohail Masood Bhatti[3], Umair Muneer Butt[4]

Dept. of Computer Science and Information Technology, Superior University, Lahore, Pakistan[1, 2, 3]

Dept. of Computer Science, The Chenab University, Gujrat, Pakistan[4]

*Abstract*—Tumor is currently the second most prevalent cause of mortality, and its prevalence is expanding rapidly. The development of pulmonary nodules inside the lungs is suggestive of the existence of lung cancer. The detection of cancer is achieved using nodules detected in computer tomography (CT) images obtained from the LUNA 16 dataset. This study uses the Python library "PyTorch" for this purpose. A three-dimensional model has been used to train and extract the nodular segments from CT-Scan images, referred to as CT-scan chunks. It is done due to the impracticality of handling the whole CT scan image due to its vast size. The previously mentioned chunks are then transformed into PyTorch tensors. The tensors are subsequently input into a deep learning model to extract features, which are then passed through a sequence of machine learning classifiers for the purpose of classification. These classifiers include Support Vector Machines, Multi-layer Perceptron, Random Forest Classifier, Logistic Regression, K Nearest Neighbor, and Linear Discriminant Analysis. Our research has shown that the use of chunk extraction from CT-Scan images, coupled with the creation of tensors using segmented CT scans, has significantly enhanced the precision of various machine learning algorithms. Additionally, this approach has the advantage of reducing the computational time during runtime. In our study, the use of Support Vector Machines yielded the best degree of accuracy, reaching 99.68%. The findings of this study have the potential to be valuable in the practical implementation of real-time lung nodule identification applications.*

*Keywords—Deep learning; lung cancer; LUNA16; machine learning; nodules; PyTorch*

## I. Introduction

Cancer is a fetal illness that kills thousands and millions of people worldwide. Lung cancer is responsible for around 350 daily fatalities, making it the second leading cause of cancer-related deaths. Roundabout 103,00 of 127 lakh lung cancer fatalities in 2023 (81%) are directly attributable to smoking. The remaining approximately 20,500 lung cancer fatalities unrelated to smoking would be classified as the eighth leading cause of cancer mortality [1]. The process of diagnosing pulmonary nodules is valuable for the identification and treatment of cancer in its initial stages, therefore significantly contributing to the preservation of many human lives [2].

Doctors have significant challenges when dealing with a substantial volume of CT-scan data. Computer-aided detection (CAD) systems have been shown to alleviate the burden of radiologists while enhancing diagnosis accuracy in the context of lung cancer [3]. The CDAM technique was used in order to visually represent the characteristics and highlight the decision-making process inside Zhang's unique CAD (Computer-Aided diagnosis) system for lung cancer diagnosis [4]. Recent research on lung nodule identification demonstrates the exceptional performance of Deep Learning (DL)-based CAD systems [5].

The use of DL techniques has shown exceptional efficacy in the domain of lung cancer diagnosis, namely in the identification of pulmonary nodules. A study used the Faster R-CNN and U-Net-like encoder-decoder models to analyze the LUNA16 dataset, resulting in an accuracy rate of 0.842 [6]. The 3D CNN model is employed by Duo et al. [7] for Lung cancer detection. The researchers partitioned their approach into two distinct components, namely candidate screening and false positive deduction. The researchers attained a sensitivity rate of 90.06% and a FROC score of 0.839. Khosravan et al. obtained a FROC score of 0.897. The researchers put out a computational procedure known as S4ND with the purpose of facilitating end-to-end learning. The architecture is comprised of densely connected CNN units [8]. Wang et al. used three slices to make a 3D-RGB image for nodule detection and achieved an accuracy of 0.968 [9].

There was a need to improve the nodule detection accuracy, so it can be effectively used in real time scenarios. Moreover, the use of three-dimensional convolutional neural network (3D-CNN) architectures has more potential in efficiently capturing the unique attributes of malignant nodules in contrast to two-dimensional CNN (2D CNN) designs. Thus far, only a limited number of publicly available research publications have been published on the use of 3D CNNs for the identification of lung cancer. This research study used 3-dimensional CT-Scan results, 3D CNN features and machine learning classifiers, using specialized Python libraries to leverage the capabilities of Python and the effectiveness of machine learning methods. Various state-of-the-art ML techniques have been proposed for the purpose of identifying lung nodules in the context of lung cancer detection in literature. However, there is ongoing debate over the efficacy of current methods for the timely identification of lung cancer. Therefore, we advocate for the adoption of a comprehensive methodology in the detection of lung cancer. The research makes many noteworthy contributions, which are outlined below:

- Nodules have been identified in the photos obtained from the publicly accessible dataset LUNA16.

- Images were preprocessed by isolating the lung region, creating slices, and then segmenting the CT-Scan

slices. Additionally, the nodule segment from the segmented slices was transformed into *CT-Scan chunks and a 3D tensor was created.*

- In our study, several machine learning classifiers for the purpose of classification are used after extracting features using 3D deep learning algorithm. These ML classifiers include Support Vector Machine, Random Forest, Machine Learning Perceptron, Logistic Regression, Linear discriminant analysis, and K Nearest Neighbors.

After this introductory section, a comprehensive assessment of the existing literature pertaining to the detection of lung cancer is presented in Section II. Subsequently, our proposed technique is outlined in Section III. The findings of the proposed methodology are provided and compared with the outcomes of state-of-the-art algorithms in Section IV along with detailed analysis and examination of the methodology used in the study, as well as a comprehensive presentation of the obtained findings. The concluding section encapsulates the research effort and its novel contributions.

## II. BACKGROUND STUDY

According to the data shown in Fig. 1, lung cancer has emerged as the second most prominent cause of mortality. Lung cancer can be diagnosed efficiently by detecting nodules in the CT scan images as shown in Fig. 2. Currently, pulmonary nodules are mostly diagnosed using various forms of chest imaging examination, such as MRI, X-ray, CT-Scan, and others. Because of its great accuracy and cheap cost, CT scan has become the gold standard in diagnostics [10]. Due to its high level of sensitivity, CT scans have become the preferred method in screening for lung cancer. Classifying pulmonary nodules, however, remains a laborious task. Furthermore, the size of CT images is continually expanding, adding more labor to the normal diagnosis procedure for radiologists [11].

Manual feature engineering is often employed in conjunction with machine learning for medical picture categorization. For both binary and multi-class classification, support vector machines (SVM) are a well-known machine learning approach. Nodule detection was performed using an adaptive morphology-based strategy and SVM [12]. Manifold classification regularization was applied by Ren et al. for nodule identification along with the Dense network of neurons (DNN) [13]. Image categorization and object recognition both benefited greatly from DNN's automatic feature extraction. In a research study, a convolutional neural network (CNN) was used for the purpose of detecting and classifying lung nodules. [14]. Classifying nodules in CT scan pictures is another application for CNN-based Generative Adversarial Networks [15]. A pulmonary nodule classification system was designed by Jiang et al. The authors used improved deep features by using contextual attention and located region of interest (ROI) using spatial attention. For enhancing the performance of the classifier an ensemble was employed [16]. CNN was used along with kernel-based non-Gaussian for cancer detection. The authors applied an adaptive histogram equalization technique in the preprocessing step for segmenting the region of interest. They have achieved an accuracy of 87% [17].
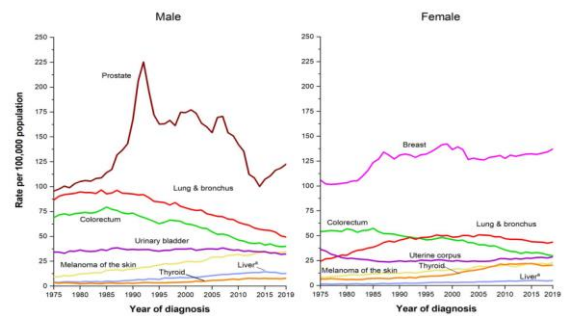


Fig. 1. Cancer incidence rates by gender in the USA from 1975 to 2019. Rates are adjusted for reporting lag times and age standardization to the US standard population of 2000 [1].



Fig. 2. Lungs images: (a) Normal lung CT image, (b) Cancerous lung CT image [49].

In a study, the deep learning model employed for nodule identification is a receptive field regularized V-net [18]. The classification of lung nodules is accomplished by the use of a hybrid approach including the SqueezeNet and ResNet models. In addition to convolutional neural networks (CNN), authors used a bio-inspired approach called the "Whale optimization algorithm with adaptive particle swarm optimization" (WOA-APSO) for detecting lung cancer [19]. They achieved an accuracy of 97.18%. Histogram equalization, the Tophat approach for noise removal, and the Boosted deep convolutional neural network (BDCNN) were utilized by Rani et al. [20] while classifying lung cancer. The noise was filtered out using weighted mean histogram analysis, and features were extracted using a hybrid dual-tree complex. Ultimately, a deep CNN was used for the purpose of lung cancer detection [21].

A sequential technique for identifying lung cancer in CT lung images was devised by Guo et al. [22]. The used approach included the utilization of both a CNN-based classifier and a feature-based classifier. The first use of a CNN-based classifier was seen in the analysis of a dataset pertaining to the detection of lung cancer. Subsequently, a classifier based on features was employed for further investigation. [22]. Irregular nodule shapes were segmented by Hesamian et al. [23]. To tackle the issue of diminished contrast, scholars have conducted investigations including the use of deep-learning methodologies on artificially created images derived from innovative color schemes. In this work, a modified version of the DL-based U-Net model was used. Chen et al. used the dense neural network methodology [24].

The usage of batch normalization and dropout was employed in conjunction with this dense architecture. The

performance on the LUNA16 dataset has been commendable. Basal et al. and Xu et al. used ensemble learning to identify lung cancer [25], [26] and combined YOLOv3 with CNN for malignant nodule detection. Fractal networks are employed in research to categorize lung nodules [27]. The performance of the system was evaluated and verified using the LUNA16 dataset, using the Fractal net model. The resulting accuracy was 94.7%. With the use of ensemble learning, Muzammil et al. improved accuracy to 96.89%. In their work [28], they integrated the SVM and AdaBoostM2 algorithms with the Linear discriminant analysis (LDA). Another research [29] used deep learning to build a segmentation technique for identifying lung cancer. Numerous more cutting-edge research [30]–[33] covered a wide range of topics and highlighted additional real-world issues.

TABLE I.        SUMMARY OF LUNG CANCER DETECTION ARTICLES

| References | Year | Method | Accuracy |
|---|---|---|---|
| [34] | 2015 | Multi-scale CNN | 86.84% |
| [35] | 2017 | Multi-crop CNN | 87.14% |
| [35] | 2017 | Deep 3D DPN | 88.74% |
| [35] | 2017 | Deep 3D DPN+ GBM | 90.44% |
| [36] | 2018 | 3D-CNN with transfer learning | 71% |
| [37] | 2018 | FR Using DAN | 93.9% |
| [38] | 2018 | Wavelet-Based CNN | 91.9% |
| [17] | 2019 | 3D Ensemble | 90.24% |
| [39] | 2019 | CNN with feature fusion | 99.2% |
| [40] | 2020 | Multi-scale CNN (MCNN) | 93.7% |
| [41] | 2020 | Kernel-based non-gaussian Convolutional Neural Network | 87.3 % |
| [19] | 2020 | WOA | 91.18% |
| [20] | 2020 | Boosted Deep Convolutional Neural Network | 97.30% |
| [42] | 2020 | TL with VGG16, VGG19 | 95.0% |
| [26] | 2020 | Deep 3D-Scan | 92.7% |
| [28] | 2021 | EL | 96.9% |
| [22] | 2021 | FB-and OCNN | 95.96% |
| [43] | 2021 | 3D attention U-Net | 94.43% |
| [44] | 2021 | Res BCDU-Net | 97.58% |
| [45] | 2021 | HMB-HCF | 99.30% |
| [46] | 2022 | YOLOv3 | 95.17% |
| [47] | 2022 | ProCAN | 95.28% |
| [18] | 2022 | Squeeze net. Res Net | 94.87% |
| [2] | 2023 | LungNet-SVM | 96.37% |

Table I provides a review of recent research that has advanced our understanding. Literature Table I illustrates the substantial amount of scholarly literature dedicated to the examination of lung cancer diagnosis, nodule detection, and

categorization. The main objective of this research is to investigate lung cancer screening. The CT scans were segmented into chunks and then subjected to analysis using a three-dimensional convolutional neural network (3D-CNN) model. Deep learning-based imaging algorithms have significantly enhanced the accuracy and efficacy of lung nodule segmentation, identification, and classification. These algorithms use old medical images to achieve superior performance in these tasks. The system's ability to engage in reinforcement learning facilitated the attainment of this outcome.
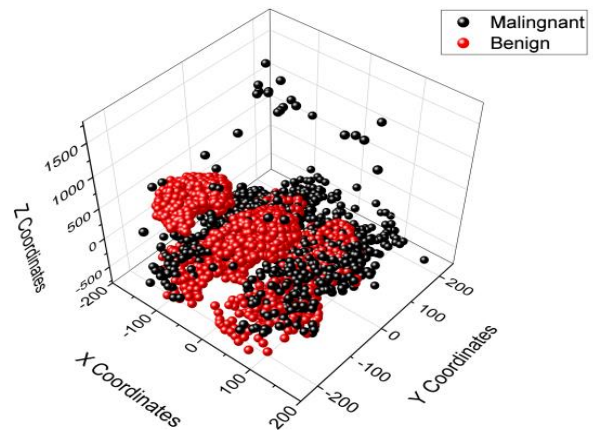


Fig. 3.    The spatial coordinates of the lesions are situated in the x, y, and z dimensions. Red colour is used to indicate benign lesions, whereas black colour is used to indicate malignant tumours [26].

An assortment of unsupervised deep learning algorithms, such as CNN, Faster R-CNN, Mask R-CNN, and U-Net have been used to create convolutional networks that aim to identify lung cancer and minimize the occurrence of false positives. This is in contradiction to the conventional approach of using supervised and reinforced learning techniques. Previous researches have shown that computed tomography (CT) is the most often used imaging modality in computer-aided detection (CAD) systems for the detection of lung cancer. The use of 3D-CNN architectures shows more promise in effectively capturing the distinctive characteristics of malignant nodules compared to 2D CNN designs. So far, only a restricted number of research articles using 3D convolutional neural networks (CNNs) for the purpose of lung cancer detection have been made accessible to the public.

III.    METHOD

In the subsequent part, we will elucidate the strategy that has been put forward. In Fig. 8 a block diagram is provided, illustrating the suggested technique. This demonstrates the detection of nodules in the images, followed by the segmentation of the CT-Scan image into distinct sections, as seen in Fig. 7. The segmentation and classification tasks were effectively accomplished by using deep learning techniques. Within the scope of this research activity, the process involves the concatenation of a 3D tensor, which is afterwards used in conjunction with machine learning algorithms, with the aim of facilitating the identification of lung cancer.

## A. Dataset

The data used in this research was obtained from Kaggle, a reputable and well-known data repository. The Lung Nodule Analysis 2016 Challenge dataset, often known as Luna16, has been released to the public. It was updated in 2020. The dataset comprises CT scans from a total of 888 patients. Every computed tomography (CT) scan has a thickness that exceeds 2.5 millimeters. The data is saved in the MetaImage format, more especially in the mhd/raw file format. Every .mhd file is accompanied by a separate binary file that contains the raw pixel data. The dataset has a total of 754,975 candidates, whose information is categorized into two distinct groups: malignant and benign. Malignant nodules are classified as "1" whereas benign nodules are classified as "0". Fig. 3 depicts the distribution of lesion sites among the patients.

## B. Preprocess

During the preprocessing phase, the following steps were conducted:

*1) Extract CT-Scan images:* The CT-Scan files were retrieved from the dataset using the "SimpleITK" package.

*2) Unique Ct scans:* We found that there are total 888 unique CT-Scans for 754975 candidates.

*3) Missing values:* The missing values in the data were examined. A total of 443 missing data were identified, indicating the absence of unique CT-Scans. Consequently, the aforementioned values were eliminated.

*4) Histogram:* The pixel values undergo a transformation to Hounsfield units (HU), and afterwards, their histograms are shown, as seen in Fig. 4. The histogram has a range of -2000 to 1000 Hounsfield Units (HU). The histograms of all the CT-scan pictures exhibit a similar distribution.

*5) Pulmunary region:* The pulmonary area is marked out by using several threshold values, as seen in Fig. 5.

## C. Process

The data is divided into training and validation. The input images are transformed in the data preprocessing step, and noise and outliers are filtered away. Data is analyzed and it is found that the candidate file has a flag for each mass in the CT scans. "seriesuid" is a unique identifier for each CT Scan. The class label is 0 if the CT-Scan doesn't have a nodule. The class label is 1, if CT scans have a nodule (both malignant and benign). There are over 750k candidates. The candidates belonging to the same CT scan are categorized into groups, after which the diameters dictionary is used to get the diameter of each candidate. The order of the applicants was flipped, resulting in all individuals with nodules being positioned at the top of the list. The candidates without comparable CT scans were excluded from the dataset. The entire number of applicants is 750,000, with just 37,000 having comparable CT scans. A chunk was obtained by generating a list consisting of three slices, with each slice corresponding to a certain direction. The segments are then transformed into PyTorch Tensors for CT-Scan analysis. Every tensor in the dataset has a shape of 1x10x18x18. These PyTorch tensors are fed into deep-learning models for feature extraction. Next, a training and testing dataset is created.
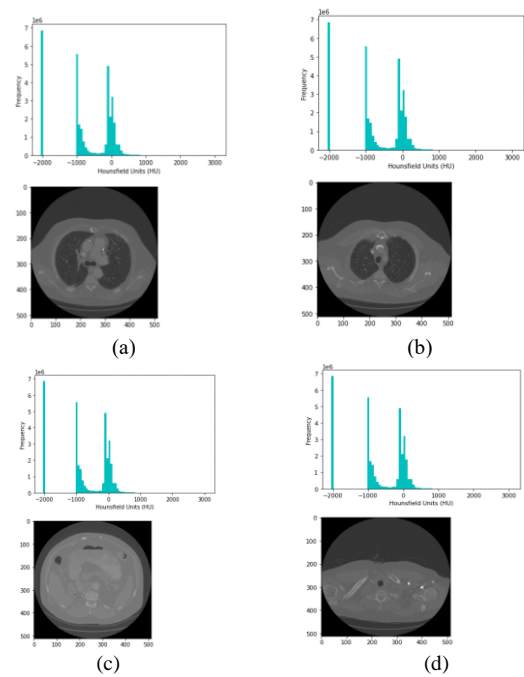


Fig. 4. CT-Scans with their corresponding histograms in HU units. (a) CT-scan number 80, (b) CT-scan number 100, (c) CT-scan number 2, (d) CT scan number 120.
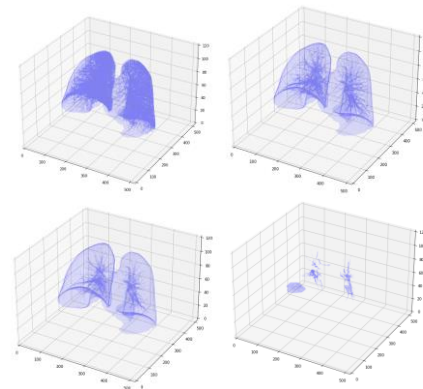


Fig. 5. 3D view of the lungs and bronchioles, for different threshold values.

The step-by-step process for carrying out experiments is as follows:

*1) Convert* the image into the fixed slices.

*2) Segment* the CT-Scan slices.

*3) Convert* the segmented CT-scan slices into 3D tensors.

*4) Split* the data into training and testing.

*5) Use* a 3D Deep learning algorithm for feature extraction.

*6) Use* machine learning classifiers for classification.

The 3D CNN model that is used for feature extraction is elaborated in Table III. The use of flattened layers involves the conversion of the output of a maxpooling layer, which is a multidimensional tensor, into a one-dimensional representation. The neural network architecture is composed

of two fully connected layers, specifically referred to as fc1 and fc2, which are positioned after the flattened layer. Fully connected layers are often used for the purpose of feature extraction. In this instance, the fc1 layer is utilized.

TABLE II. COMPARISON OF PROPOSED MODEL WITH STATE-OF-THE-ART ALGORITHMS

| Authors | Year | Dataset | Method | Accuracy |
|---|---|---|---|---|
| Shah et al. [42] | 2020 | LUNA16 | Transfer Learning VGG16, VGG19 | 95.0% |
| Bansal et al [26] | 2020 | LUNA16 | Deep3DScan | 92.7% |
| Naik et al.[27] | 2021 | LUNA16 | FractalNet + CNN | 94.7% |
| Muzammil et al. [28] | 2021 | LUNA16 | Ensemble Learning | 96.8% |
| Dodia et al.[18] | 2022 | LUNA16 | Squeeze Net + Resnet | 94.87% |
| Naseer et al.[2] | 2023 | LUNA16 | LungNet-SVM | 97.64% |
| **Proposed method** | 2023 | LUNA16 | 3D Tensors with Transfer learning (3D CNN + SVM) | **99.6%** |

TABLE III. 3D-CNN MODEL'S PARAMETERS

| Sr No. | Layer | Input Channel | Kernels, size | Parameters | Output shape |
|---|---|---|---|---|---|
| 1. | Conv3D-1 | 1 | (3,3,3) | 896 | [-1,32,10,18,18] |
| 2 | ReLU-2 | 32 | ---- | 0 | [-1,32,10,18,18] |
| 3 | MaxPool3D-3 | 32 | (2,2,2) | 0 | [-1,32,5,9,9] |
| 4 | Conv3D-4 | 32 | (3,3,3) | 55,360 | [-1,64.5.9.9] |
| 5 | ReLU-5 | 64 | | 0 | [-1,64,5,9,9] |
| 6 | MaxPool3D-6 | 64 | (2,2,2) | 0 | [-1,64,2,4,4] |
| 7 | Flatten-7 | 64 | NULL | NULL | [-1,1024] |

TABLE IV. ABBRIVIATIONS AND THEIR EXPLANATIONS USED IN THIS STUDY

| Abbreviation | Explanation |
|---|---|
| CT-Scans | Computer Tomography Scans |
| CDAM | Channel-dependent activation mapping |
| CAD | Computer-Aided Design |
| DL | Deep Learning |
| DNN | Deep Neural Network |
| FROC | Free-Response Receiver Operating Characteristic |
| ML | Machine Learning |
| MRI | Magnetic Resonance Imaging |
| SVM | Support Vector Machines |
| ROI | Region of Interest |
| BDCNN | Boosted deep convolutional neural network |
| YOLO | You only look once |
| LUNA | LUng Nodule Analysis |
| LDA | Linear discriminant analysis |
| Seg3DT_SVM | Segmented 3D Tensors and Support Vector Machines |

## IV. RESULTS AND DISCUSSION

In this research study, a deep learning model is used for the purpose of feature extraction. Prior to this, the data is subjected to preprocessing, whereby it is transformed into three-dimensional CT-scan chunks to serve as input. The machine learning classifiers use these characteristics in order to do classification. The transfer learning technique has been used in our study. The LUNA16 [48] benchmark dataset is used for training and validating this model. The dataset comprises a collection of 1,018 CT scan pictures. The training dataset accounts for 80% of the data, whilst the remaining 20% is allocated for validation purposes. In this research, the suggested model was evaluated using accuracy, which is a commonly used metric for assessing performance.

Accuracy is defined as:

$$\text{Accuracy} = (TN + TP) / (TN + FN + FP + TP) \qquad (1)$$

The variables TN and TP in equation (1) represent the rates of true negative and true positive, respectively, in the confusion matrix. A confusion matrix is shown in Fig. 9. In this research work, data is pre-processed, features are extracted and then machine learning algorithms are applied at the end of pipeline. The performance of the suggested model is evaluated and compared with other contemporary approaches, as shown in Table II. A more comprehensive assessment of the resilience of the suggested model may be obtained by referring to Fig. 10. Fig. 11 illustrates the accuracy of all the classifiers used in this investigation.

The findings clearly demonstrate that the suggested model has surpassed the performance of existing algorithms by attaining an accuracy rate of 99.6%. Hence, this model has the capability to be used in real-time situations for the purpose of identifying lung malignancies. One disadvantage of this work is that the suggested model is built using just one dataset. To assess the robustness of the model, it will be applied to several datasets. The abbreviations used in this research study are shown in Table IV.

This research study presents a unique methodology for the identification of lung cancer. The task of lung cancer detection is accomplished by the use of data collection that is accessible to the general public. The data used in this study was acquired from Kaggle, a well-known and esteemed data source. The publicly available dataset, referred to as the Lung Nodule Analysis 2016 Challenge dataset or Luna16, has been made accessible. The information has been revised in the year 2020. The dataset consists of computed tomography (CT) images obtained from a total of 888 individuals. The data is stored in the MetaImage format, specifically in the mhd/raw file format. Each .mhd file is accompanied by an independent binary file that includes the unprocessed pixel data. The dataset comprises a total of 754,975 individuals, with their information classified into two separate categories: malignant and non-cancerous. In the preprocessing stage, the CT-Scan files were obtained from the dataset using the "SimpleITK" function. There were a total of 888 distinct CT scans among the 754,975 individuals included in our analysis (Fig. 6).
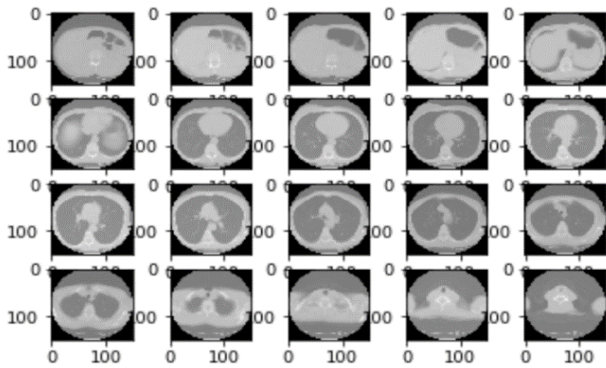
Fig. 6.    CT-Scan slices.
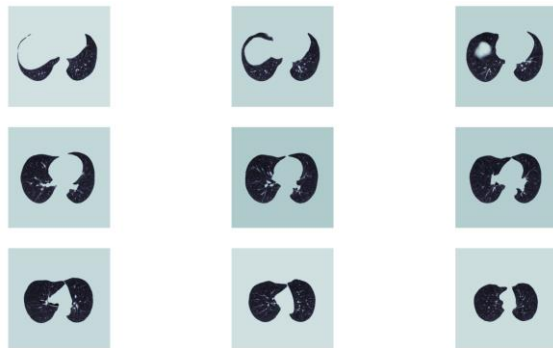


Fig. 7.    CT-Scan segmented slices.
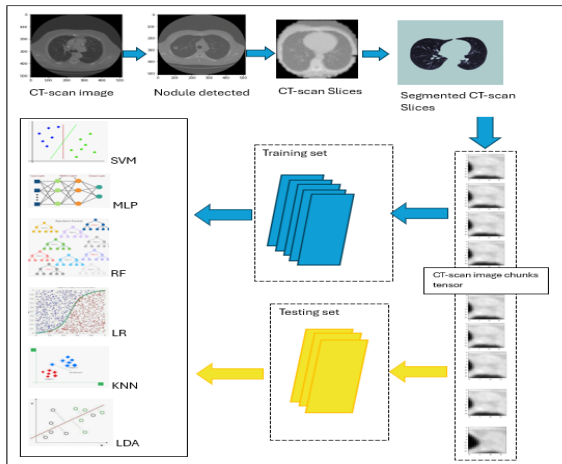


Fig. 8.        Block diagram of this research work.



Fig. 9.    Confusion matrix [50].
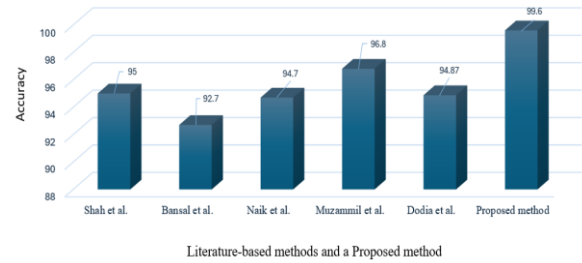


Fig. 10.  Comparison of state-of-the-art accuracies with the proposed method.
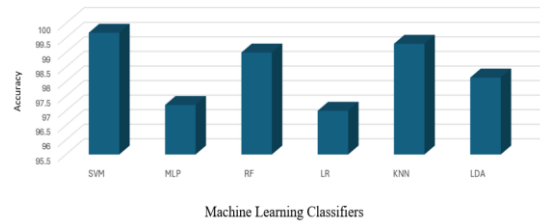


Fig. 11.  Accuracies of various classifiers, using the proposed preprocessing method.

The examination of missing values in the dataset was conducted. A total of 443 instances of missing data were detected, suggesting the lack of distinct CT-Scans. As a result, the previously indicated values were eradicated. The pixel values are subjected to a conversion process into Hounsfield units (HU), and subsequently, their histograms are shown, as seen in Fig. 4. The histogram exhibits a range spanning from -2000 to 1000 Hounsfield Units (HU). The histograms of all the CT-scan images show a comparable distribution. The delineation of the pulmonary region is achieved by the use of several threshold values, as seen in Fig. 5. The dataset is partitioned into two subsets, namely the training set and the validation set. During the data preparation stage, the input pictures undergo a transformation process, which includes the removal of noise and outliers. Upon analysis of the data, it has been determined that the candidate file contains a flag for each mass seen in the CT images that serves as a unique identifier for each CT-Scan. The assigned class label is 0 in cases when the CT-Scan does not reveal the presence of a nodule. The assigned class label is denoted as 1, indicating the presence of nodules in CT scans, including both malignant and benign cases. There are a total of more than 750,000 candidates. The candidates belonging to the same CT scan are categorized into groups, after which the diameters dictionary is used to get the diameter of each candidate. The order of the applicants was reversed, resulting in all individuals with nodules being placed at the top of the list. The individuals who did not have CT scans that could be compared were eliminated from the dataset. The procedure of segmentation has considerable significance within the realm of diagnostics.

The extraction of CT scan slices from images is performed in order to eliminate any unwanted portions. The lung pictures were then subjected to segmentation. The extraction of three-dimensional segments includes nodules from the segmented slices. The parts are put into our model. The chunk's measurements are 10 units in length, 18 units in breadth, and

18 units in height. A chunk was acquired by constructing a list including three slices, where each slice corresponds to a certain direction. The segments are then converted into PyTorch Tensors to facilitate CT-Scan processing. The PyTorch tensors are used as inputs in 3D deep learning models for feature extraction. Following this, a dataset is constructed for the purpose of training and testing, and a variety of machine learning classifiers are used to choose the classifier that exhibits the highest performance. The results unequivocally indicate that the proposed model has outperformed current algorithms, achieving a remarkable accuracy rate of 99.68%. Therefore, this model has the capacity to be used in real-time scenarios with the objective of detecting lung cancers.

## V. CONCLUSION

This study presents a novel approach that utilizes segmented 3D tensors, 3D convolutional neural network and SVM to identify lung nodules in computed tomography (CT) data. The proposed model is abbreviated as Seg3DT_SVM. The model being discussed is specifically built to accept data chunks in the format of PyTorch tensors. The discrete components, referred to as chunks, that comprise the nodule are the individual segments of computed tomography (CT) slices used. The process of obtaining cross-sectional images is an essential element of computed tomography (CT) scans. The proposed technique includes an initial phase of data preparation, as previously elucidated, succeeded by the use of machine learning algorithms. The experimental investigation used the publicly available LUNA16 dataset and was conducted using the PyTorch framework. The analyzed model demonstrates a much greater degree of accuracy (99.68%) compared to the existing state-of-the-art approaches used for the same dataset. The method demonstrates the capability to assist healthcare workers in promptly identifying cases of lung cancer in real-time situations.

## REFERENCES

[1] R. L. Siegel, K. D. Miller, N. S. Wagle, and A. Jemal, "Cancer statistics, 2023," CA Cancer J Clin, vol. 73, no. 1, pp. 17–48, Jan. 2023, doi: 10.3322/caac.21763.

[2] I. Naseer, T. Masood, S. Akram, A. Jaffar, M. Rashid, and M. A. Iqbal, "Lung Cancer Detection Using Modified AlexNet Architecture and Support Vector Machine," Computers, Materials and Continua, vol. 74, no. 1, pp. 2039–2054, 2023, doi: 10.32604/cmc.2023.032927.

[3] D. Liu, F. Liu, Y. Tie, L. Qi, and F. Wang, "Res-trans networks for lung nodule classification," Int J Comput Assist Radiol Surg, vol. 17, no. 6, pp. 1059–1068, Jun. 2022, doi: 10.1007/S11548-022-02576-5.

[4] S. Zheng et al., "Interpretative computer-aided lung cancer diagnosis," Comput Methods Programs Biomed, vol. 210, Oct. 2021, doi: 10.1016/J.CMPB.2021.106363.

[5] H. Jiang, F. Shen, F. Gao, and W. Han, "Learning Efficient, Explainable and Discriminative Representations for Pulmonary Nodules Classification," Jan. 2021, [Online]. Available: http://arxiv.org/abs/2101.07429

[6] A. A. A. Setio et al., "Validation, comparison, and combination of algorithms for automatic detection of pulmonary nodules in computed tomography images: The LUNA16 challenge," Med Image Anal, vol. 42, pp. 1–13, Dec. 2017, doi: 10.1016/j.media.2017.06.015.

[7] Q. Dou, H. Chen, Y. Jin, H. Lin, J. Qin, and P.-A. Heng, "Automated Pulmonary Nodule Detection via 3D ConvNets with Online Sample Filtering and Hybrid-Loss Residual Learning," Aug. 2017, [Online]. Available: http://arxiv.org/abs/1708.03867

[8] N. Khosravan and U. Bagci, "S4ND: Single-Shot Single-Scale Lung Nodule Detection," May 2018, [Online]. Available: http://arxiv.org/abs/1805.02279

[9] J. Wang et al., "Pulmonary Nodule Detection in Volumetric Chest CT Scans Using CNNs-Based Nodule-Size-Adaptive Detection and Classification," IEEE Access, vol. 7, pp. 46033–46044, 2019, doi: 10.1109/ACCESS.2019.2908195.

[10] A. Pezeshk, S. Hamidian, N. Petrick, and B. Sahiner, "3-D Convolutional Neural Networks for Automatic Detection of Pulmonary Nodules in Chest CT," IEEE J Biomed Health Inform, vol. 23, no. 5, pp. 2080–2090, Sep. 2019, doi: 10.1109/JBHI.2018.2879449.

[11] S. P. Pawar and S. N. Talbar, "LungSeg-Net: Lung field segmentation using generative adversarial network," Biomed Signal Process Control, vol. 64, Feb. 2021, doi: 10.1016/j.bspc.2020.102296.

[12] A. Halder, S. Chatterjee, D. Dey, S. Kole, and S. Munshi, "An adaptive morphology based segmentation technique for lung nodule detection in thoracic CT image," Comput Methods Programs Biomed, vol. 197, p. 105720, Dec. 2020, doi: 10.1016/J.CMPB.2020.105720.

[13] Y. Ren et al., "A manifold learning regularization approach to enhance 3D CT image-based lung nodule classification," Int J Comput Assist Radiol Surg, vol. 15, no. 2, pp. 287–295, Feb. 2020, doi: 10.1007/S11548-019-02097-8.

[14] L. Alzubaidi et al., "Review of deep learning: concepts, CNN architectures, challenges, applications, future directions," J Big Data, vol. 8, no. 1, Dec. 2021, doi: 10.1186/s40537-021-00444-8.

[15] Y. Onishi et al., "Multiplanar analysis for pulmonary nodule classification in CT images using deep convolutional neural network and generative adversarial networks," Int J Comput Assist Radiol Surg, vol. 15, no. 1, pp. 173–178, Jan. 2020, doi: 10.1007/S11548-019-02092-Z.

[16] K. Xia, J. Chi, Y. Gao, Y. Jiang, and C. Wu, "Adaptive aggregated attention network for pulmonary nodule classification," Applied Sciences (Switzerland), vol. 11, no. 2, pp. 1–15, Jan. 2021, doi: 10.3390/app11020610.

[17] H. Jiang, F. Gao, X. Xu, F. Huang, and S. Zhu, "Attentive and ensemble 3D dual path networks for pulmonary nodules classification," Neurocomputing, vol. 398, pp. 422–430, Jul. 2020, doi: 10.1016/J.NEUCOM.2019.03.103.

[18] S. Dodia, A. Basava, and M. Padukudru Anand, "A novel receptive field-regularized V-net and nodule classification network for lung nodule detection," Int J Imaging Syst Technol, vol. 32, no. 1, pp. 88–101, Jan. 2022, doi: 10.1002/IMA.22636.

[19] S. Vijh, P. Gaurav, and H. M. Pandey, "Hybrid bio-inspired algorithm and convolutional neural network for automatic lung tumor detection," Neural Comput Appl, 2020, doi: 10.1007/s00521-020-05362-z.

[20] K. V. Rani and S. J. Jawhar, "Superpixel with nanoscale imaging and boosted deep convolutional neural network concept for lung tumor classification," Int J Imaging Syst Technol, vol. 30, no. 4, pp. 899–915, Dec. 2020, doi: 10.1002/IMA.22422.

[21] A. D. Ananth and C. Palanisamy, "Extended and optimized deep convolutional neural network-based lung tumor identification in big data," Int J Imaging Syst Technol, vol. 32, no. 3, pp. 918–934, May 2022, doi: 10.1002/IMA.22667.

[22] Z. Guo, L. Xu, Y. Si, and N. Razmjooy, "Novel computer-aided lung cancer detection based on convolutional neural network-based and feature-based classifiers using metaheuristics," Int J Imaging Syst Technol, vol. 31, no. 4, pp. 1954–1969, Dec. 2021, doi: 10.1002/IMA.22608.

[23] M. H. Hesamian, W. Jia, X. He, Q. Wang, and P. J. Kennedy, "Synthetic CT images for semi-sequential detection and segmentation of lung nodules," Applied Intelligence, vol. 51, no. 3, pp. 1616–1628, Mar. 2021, doi: 10.1007/s10489-020-01914-x.

[24] Y. Chen, Y. Wang, F. Hu, L. Feng, T. Zhou, and C. Zheng, "Ldnnet: Towards robust classification of lung nodule and cancer using lung dense neural network," IEEE Access, vol. 9, pp. 50301–50320, 2021, doi: 10.1109/ACCESS.2021.3068896.

[25] Y. Xu et al., "Identification of Benign and Malignant Lung Nodules in CT Images Based on Ensemble Learning Method," Interdiscip Sci, vol. 14, no. 1, pp. 130–140, Mar. 2022, doi: 10.1007/S12539-021-00472-1/METRICS.

[26] G. Bansal, V. Chamola, P. Narang, S. Kumar, and S. Raman, "Deep3DScan: Deep residual network and morphological descriptor based framework for lung cancer classification and 3D segmentation," IET Image Process, vol. 14, no. 7, pp. 1316–1326, May 2020, doi: 10.1049/iet-ipr.2019.1164.

[27] A. Naik, D. R. Edla, and V. Kuppili, "Lung Nodule Classification on Computed Tomography Images Using Fractalnet," Wirel Pers Commun, vol. 119, no. 2, pp. 1209–1229, Jul. 2021, doi: 10.1007/S11277-021-08258-W/METRICS.

[28] M. Muzammil, I. Ali, I. U. Haq, A. A. Khaliq, and S. Abdullah, "Pulmonary nodule classification using feature and ensemble learning-based fusion techniques," IEEE Access, vol. 9, pp. 113415–113427, 2021, doi: 10.1109/ACCESS.2021.3102707.

[29] A. Shimazaki et al., "Deep learning-based algorithm for lung cancer detection on chest radiographs using the segmentation method," Sci Rep, vol. 12, no. 1, Dec. 2022, doi: 10.1038/s41598-021-04667-w.

[30] S. Su, D. Yuan, Y. Wang, and M. Ding, "Fine Grained Feature Extraction Model of Riot-related Images Based on YOLOv5," Computer Systems Science and Engineering, vol. 45, no. 1, pp. 85–97, 2023, doi: 10.32604/csse.2023.030849.

[31] H. Sun and R. Grishman, "Lexicalized Dependency Paths Based Supervised Learning for Relation Extraction," Computer Systems Science and Engineering, vol. 43, no. 3, pp. 861–870, 2022, doi: 10.32604/csse.2022.030759.

[32] W. Sun, Y. Du, X. Zhang, and G. Zhang, "Detection and recognition of text traffic signs above the road," International Journal of Sensor Networks, vol. 35, no. 2, pp. 69–78, 2021, doi: 10.1504/IJSNET.2021.113626.

[33] H. Sun and R. Grishman, "Employing Lexicalized Dependency Paths for Active Learning of Relation Extraction," Intelligent Automation and Soft Computing, vol. 34, no. 3, pp. 1415–1423, 2022, doi: 10.32604/iasc.2022.030794.

[34] W. Shen, M. Zhou, F. Yang, C. Yang, and J. Tian, "Multi-scale Convolutional Neural Networks for Lung Nodule Classification," Inf Process Med Imaging, vol. 24, pp. 588–599, 2015, doi: 10.1007/978-3-319-19992-4_46.

[35] W. Shen et al., "Multi-crop Convolutional Neural Networks for lung nodule malignancy suspiciousness classification," Pattern Recognit, vol. 61, pp. 663–673, Jan. 2017, doi: 10.1016/j.patcog.2016.05.029.

[36] W. Lindsay, J. Wang, N. Sachs, E. Barbosa, and J. Gee, "Transfer Learning Approach to Predict Biopsy-Confirmed Malignancy of Lung Nodules from Imaging Data: A Pilot Study," Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics), vol. 11040 LNCS, pp. 295–301, 2018, doi: 10.1007/978-3-030-00946-5_29.

[37] K. Mao, R. Tang, X. Wang, W. Zhang, and H. Wu, "Feature Representation Using Deep Autoencoder for Lung Nodule Image Classification," Complexity, vol. 2018, 2018, doi: 10.1155/2018/3078374.

[38] E. Matsuyama and D.-Y. Tsai, "Automated Classification of Lung Diseases in Computed Tomography Images Using a Wavelet Based Convolutional Neural Network," J Biomed Sci Eng, vol. 11, no. 10, pp. 263–274, 2018, doi: 10.4236/jbise.2018.1110022.

[39] A. Kumar, M. Fulham, D. Feng, and J. Kim, "Co-Learning Feature Fusion Maps from PET-CT Images of Lung Cancer," 2019. [Online]. Available: http://ieeexplore.ieee.org.

[40] H. Yektaei and M. Manthouri, "DIAGNOSIS of LUNG CANCER USING MULTISCALE CONVOLUTIONAL NEURAL NETWORK," Biomed Eng (Singapore), vol. 32, no. 5, Oct. 2020, doi: 10.4015/S1016237220500301.

[41] S. R. Jena and S. T. George, "Morphological feature extraction and KNG-CNN classification of CT images for early lung cancer detection," Int J Imaging Syst Technol, vol. 30, no. 4, pp. 1324–1336, Dec. 2020, doi: 10.1002/IMA.22445.

[42] G. Shah, R. Thammasudjarit, A. Thakkinstian, and T. Suwatanapongched, "NoduleNet: A Lung Nodule Classification Using Deep Learning," Ramathibodi Medical Journal, vol. 43, no. 4, pp. 11–19, Dec. 2020, doi: 10.33165/RMJ.2020.43.4.241727.

[43] C. Chen et al., "An Effective Deep Neural Network for Lung Lesions Segmentation from COVID-19 CT Images," IEEE Trans Industr Inform, vol. 17, no. 9, pp. 6528–6538, Sep. 2021, doi: 10.1109/TII.2021.3059023.

[44] Y. Jalali, M. Fateh, M. Rezvani, V. Abolghasemi, and M. H. Anisi, "ResBCDU-net: A deep learning framework for lung CT image segmentation," Sensors (Switzerland), vol. 21, no. 1, pp. 1–24, Jan. 2021, doi: 10.3390/s21010268.

[45] H. M. Balaha, M. H. Balaha, and H. A. Ali, "Hybrid COVID-19 segmentation and recognition framework (HMB-HCF) using deep learning and genetic algorithms," Artif Intell Med, vol. 119, Sep. 2021, doi: 10.1016/j.artmed.2021.102156.

[46] Z. Bu et al., "Lung Nodule Detection Based on YOLOv3 Deep Learning with Limited Datasets," MCB Molecular and Cellular Biomechanics, vol. 19, no. 1, pp. 17–28, 2022, doi: 10.32604/mcb.2022.018318.

[47] M. Al-Shabi, K. Shak, and M. Tan, "ProCAN: Progressive growing channel attentive non-local network for lung nodule classification," Pattern Recognit, vol. 122, p. 108309, Feb. 2022, doi: 10.1016/J.PATCOG.2021.108309.

[48] "Luna16 | Kaggle." Accessed: Sep. 03, 2023. [Online]. Available: https://www.kaggle.com/datasets/avc0706/luna16

[49] M. Toğaçar, B. Ergen, and Z. Cömert, "Detection of lung cancer on chest CT images using minimum redundancy maximum relevance feature selection method with convolutional neural networks," Biocybern Biomed Eng, vol. 40, no. 1, pp. 23–39, Jan. 2020, doi: 10.1016/J.BBE.2019.11.004.

[50] A. Suresh, "What is a confusion matrix?. Everything you Should Know about… | by Anuganti Suresh | Analytics Vidhya | Medium." Accessed: Sep. 03, 2023. [Online]. Available: https://medium.com/analytics-vidhya/what-is-a-confusion-matrix-d1c0f8feda5

# Early Detection and Defense Countermeasure Inference of Ransomware based on API Sequence

Shuqin Zhang, Tianhui Du[*], Peiyu Shi, Xinyu Su, Yunfei Han

School of Computer Science, Zhongyuan University of Technology, Zhengzhou, HEN037, China

*Abstract*—Currently, ransomware attacks have become an important threat in the field of network security. The detection and defense of ransomware has become particularly important. However, due to the insufficient data and behavior patterns collected dynamically to detect variants and unknown ransomware, there is also a lack of specialized defense strategies for ransomware. In response to this situation, this article proposes a ransomware early detection and defense system (REDDS) based on application programming interface (API) sequences. REDDS first dynamically collects API sequences from the pre-encryption stage of the ransomware, and calculates the API sequences as feature vectors using the n-gram model and TF-IDF algorithm. Due to the limitations of dynamic data collection, API sequences were enhanced using Wasserstein GAN with Gradient Penalty (WGAN GP), and then machine learning classification algorithms were used to train the enhanced data to detect ransomware. By mapping the malicious API of ransomware to public security knowledge bases such as Adversarial Tactics, Techniques, and Common Knowledge (ATT&CK), a Ransomware Defense Countermeasures Ontology (RDCO) is proposed. Based on the ontology model, a set of inference rules is designed to automatically infer the defense countermeasures of ransomware. The experimental results show that WGAN-GP can more effectively enhance API sequence data than other GAN models. After data augmentation, the accuracy of machine learning detection models has significantly improved, with a maximum of 99.32%. Based on malicious APIs in ransomware, defense countermeasures can be inferred to help security managers respond to ransomware attacks and deploy appropriate security solutions.

*Keywords*—*Ransomware detection; API sequences; WGAN-GP; ATT&CK; machine learning; ontology; defense countermeasures*

## I. INTRODUCTION

In recent years, ransomware attacks have sharply increased, especially during the COVID-19 pandemic. This is because many companies and organizations require remote work, and their network security measures may not be sufficient to cope with the risks brought by remote work. In addition, ransomware developers are using increasingly complex technologies and means, making it more difficult to defend against ransomware. In recent years, some famous ransomware attacks have included WannaCry, Petya/NotPetya, and Ryuk. These attacks have caused significant economic losses and data breaches, affecting thousands of organizations and individual users. These events have elevated ransomware to a level of national security concern, prompting the US Department of Justice to classify such attacks as terrorist attacks [1].

Ransomware attacks can be divided into two categories: encrypted ransomware and locked ransomware. The characteristic of encryption ransomware is its ability to encrypt files, making it impossible for victims without decryption keys to move. Lock screen ransomware can lock the screen or operating system of the victim's host after infecting it [2]. Currently, among the publicly available ransomware, encrypted ransomware is the most common type [3-6]. Therefore, this article focuses on encrypted ransomware as the research object, and the "ransomware" mentioned below when not specifically mentioned are all encrypted ransomware.

After the ransomware completes the encryption of specific files on the victim host, these files on the victim host will lose availability and be difficult to decrypt without paying a ransom [7]. Even if file recovery can be achieved through early backup, there may still be situations where information systems or files cannot be used normally during the recovery period, which affects the normal operation of enterprise business [8]. Therefore, it is particularly important to accurately detect and defend against ransomware before encrypting files. After the ransomware infects the host, it will encrypt the files in the infected host as soon as possible, so in a short period of time, the ransomware will perform a large number of operations [9], calling a large number of application programming interfaces. Taking API sequences as the analysis object, detecting and responding to targeted defense strategies in the early stages of ransomware operation is a feasible technical means.

However, traditional malware dynamic detection methods often only collect limited API sequences of ransomware, lacking sufficient data and behavior patterns to detect the increasing variety of ransomware and unknown ransomware. At present, there is a lack of defense measures against ransomware, and relying solely on data backup is not enough to cope with the continuous emergence of ransomware and its variants. To address this challenge, a combination of ATT&CK framework and D3FEND can be used to combat ransomware attacks. The ATT&CK framework is a knowledge base developed by MITRE company for describing and organizing network attack techniques. This framework provides rich information about the behavior of attackers, including the various stages and potential attack modes of ransomware attacks. By combining the knowledge of the ATT&CK framework, it is possible to better understand the behavior patterns of ransomware and establish more effective defense strategies. D3FEND is a framework used to describe and organize defensive measures. It provides defense

strategies and control measures for different ATT&CK attack technologies. By comparing with the D3FEND framework, it can be ensured that appropriate security measures have been taken and loopholes in existing defense strategies can be filled.

In response to the above issues, this article proposes a ransomware early detection and defense system (REDDS) based on API sequences. In order to address the limitations of the API dataset collected by ransomware for dynamic analysis of samples, this article innovatively applies WGAN-GP [10] technology to ransomware detection. WGAN-GP has better training stability and better generalization ability than other Generative adversarial network, and the data quality generated by WGAN-GP is higher. In addition, this paper conducts in-depth research and analysis on the relationship between the specific API of ransomware and security knowledge sources such as ATT&CK, builds a ransomware defensive countermeasures ontology (RDCO), and designs Rule of inference to derive the defense countermeasures of ransomware. Starting from APIs to defend ransomware provides a new idea and method for the defense of ransomware, and has broad application prospects in practical applications. REDDS collects a certain number of pre-encrypted API sequences from normal software and ransomware, and generates feature vectors through n-gram [11] and Term Frequency Inverse Document Frequency (TF-IDF) [12]. WGAN-GP is used to enhance API sequence data, and machine learning classification algorithms are used to train pre and post enhancement data to detect ransomware. And Rules of inference are used to infer the defense countermeasures against the malicious API of ransomware, as well as the timely response and defense of ransomware. The main contributions of this article are as follows:

*1) A* novel early detection and defense system for ransomware based on API sequences has been proposed. The system uses n-gram and TF-IDF to generate API feature vectors, and utilizes WGAN-GP for data augmentation, thereby improving the robustness and accuracy of early detection models.

*2) REDDS* constructs a ransomware defense ontology by analyzing the mapping relationship between malicious APIs in ransomware and attack techniques in ATT&CK. The ontology integrates multiple security knowledge bases, and designs Rule of inference from the malicious API to derive defense countermeasures against ransomware attacks.

*3) In the* experiment, 86 ransomware samples from 24 different families and 40 normal software were used to evaluate REDDS. The results indicate that WGAN-GP generates better API data quality than other GAN models, and data augmentation significantly improves the accuracy of the detection model. It can also infer defense countermeasures against malicious APIs.

The remainder of this paper is organized as follows. Related work is presented in Section II. Section III presents the system design of REDDS. Section IV constructs the RDCO ontology and ontology-based reasoning defense countermeasures, and Section V presents the experimental

results and evaluation of the system. Finally, Section VI concludes the paper.

## II. RELATED WORK

The huge losses and harms caused by ransomware to enterprises or organizations have become the main security threat to the cyberspace. In order to respond to ransomware attacks and ensure the security of the network environment, the detection and protection of ransomware has become a hot topic in the field of cyberspace security. Based on the theme of this article, this section briefly summarizes the application of early detection of ransomware, generation of adversarial networks in the field of security, and related research in the field of ontology-based malware analysis.

### A. Early Detection of Ransomware

Due to the fact that ransomware quickly encrypts files after infecting a host, early detection is of great significance for file protection and timely defense of infected hosts. Morato et al. [13] used SMB traffic in network shared volumes for early detection of ransomware, using 19 different series of ransomware to test the practical application of algorithms. Chen Changqing et al. [3] proposed the concept of critical time period (CTP) for ransomware detection, using machine learning for early detection based on 78 API short sequences called by ransomware during execution within CTP. Al Rimy et al. [14] applied feature selection technology based on mutual information to early detection of ransomware. This method can obtain good detection accuracy by using features extracted and selected from the behavior data of limited ransomware at the initial stage of operation. Mehnaz et al. [15] proposed a ransomware detection mechanism that detects encrypted ransomware in real-time by deploying bait technology, carefully monitoring running processes and malicious activities in file systems, and evaluating the system using samples from 14 of the most popular ransomware families. Roy et al. [16] applied BiLSTM and fully connected layers to simulate the normal state of hosts in operating enterprise systems, and detected ransomware from a large amount of environmental host log data. Execute 17 ransomware attacks on the victim host, and use the infected host log to record data validation to verify the system. The above work achieved good detection accuracy in the early detection of ransomware, but lacked sufficient data to verify the behavior of ransomware in the pre-encryption stage, and did not involve defense measures against ransomware.

### B. Application of Generative Adversarial Networks in the Field of Security

In the field of security, the limitations of dynamically collecting attack data can lead to limited or unbalanced datasets. Therefore, some studies have applied GAN for data augmentation in their work. Liu et al. [17] proposed an intrusion detection method based on the oversampling technology of WGAN-GP and feature selection, conducted experiments on three intrusion detection data sets, and improved the detection performance of the machine learning model, but their work did not evaluate the samples generated by WGAN-GP. Hu et al. [18] used the algorithm MalGAN based on generative adversarial networks (GANs) to generate

adversarial malware examples, which can bypass detection models based on black box machine learning. Yilmaz et al. [19] proposed an intrusion detection method based on GAN and MLP. GAN was used to generate three types of attacks in the UGR 16 dataset to balance the dataset. The experimental results indicate that GAN's balanced attack sample dataset produces more accurate results than the imbalanced attack sample dataset. Wu Yangming et al. [20] used a deep learning intrusion detection method based on WGAN-GP data augmentation and combined deep belief networks and extreme learning machines. The proposed algorithm was tested using the CICIDS2017 dataset, and comparative experiments showed that the method had higher accuracy and faster convergence speed. In this paper, we build an API sequence generative model based on WGAN-GP ransomware to generate high-quality API sequence samples. Evaluate the generation ability of WGAN-GP by comparing it with other GAN models, and finally prove through comparative experiments that the detection results after using WGAN-GP are better.

## C. The Use of Ontology in the Field of Malicious Software Research

Ontology is used to describe information objects for domain knowledge sharing and reuse [21]. In the field of information security, ontology has been used to characterize the behavior of malware, and build the knowledge representation of malware [22], so as to realize the analysis and reasoning of malware. Rastogi et al. [23] designed a malware ontology called MALOnt, which includes concepts such as malware features, attack behavior, and detailed information about attackers. It supports collecting intelligence on malware threats from different online sources and constructs a knowledge graph framework based on MALOnt. Ding et al. [24] designed conceptual classes and object attributes for malware, and proposed methods to represent the semantics of malware behavior. And use the Apriori algorithm to classify the malware family. This article designs a ransomware defense strategy ontology, which includes information about the characteristics of ransomware malicious APIs and related defense strategies. Design inference rules based on semantic web rule language, use rule inference engines to infer the knowledge, determine which APIs are malicious, and generate corresponding defense strategies for these APIs. In this way, when a ransomware attack occurs, the system can defend against the attack based on the inferred countermeasures.

## III. RANSOMWARE EARLY DETECTION AND DEFENSE SYSTEM

This article proposes an early detection and defense system for encrypted ransomware in the pre-encryption stage based on API sequences, as shown in Fig. 1. The system focuses on API calls during the pre-encryption phase after starting operation. In order to compensate for the insufficient data collected during the pre-encryption phase of ransomware attacks, WGAN-GP's data augmentation method is used to generate API sequence samples, and the enhanced API sequence dataset is used to train the detection model. For the defense of ransomware, by mapping the API of ransomware

with ATT&CK technology, integrating ATT&CK, D3FEND, and other security knowledge sources, and constructing a ransomware defense strategy ontology, the defense strategy is inferred based on the API of ransomware for reference by security personnel. REDDS includes four modules: API sequence collection, feature calculation, data enhancement and detection, and defense strategy inference. Below are detailed explanations of these four modules.
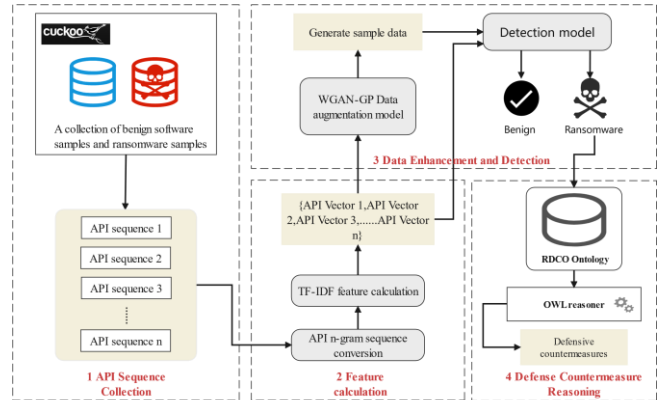


Fig. 1. REDDS execution framework.

## A. The Pre-Encryption Phase of Ransomware Collects API Sequences

The attack process of ransomware can be divided into four stages: system infection, file traversal and encryption, ransom collection and file decryption [14], among which the encryption operation was previously referred to as the pre-encryption stage. In the system infection stage, the ransomware infected the victim host through phishing, web hanging horses, exploit and other ways. After infecting the system, ransomware usually performs a series of operations such as file search and identification, file encryption, etc. [6]. Once these operations are completed, all specific files in the infected host will be encrypted; During the ransom stage, the victim is informed of how to pay the ransom through ransom text; After the victim user pays a ransom, they enter the file decryption stage, and the attacker releases the decryption device to decrypt the encrypted file. In reality, it would be meaningless to check out all files on the victim host after the ransomware completes encryption [25]. Therefore, how to accurately detect ransomware during its pre-encryption stage is a key issue in ransomware defense.

According to the execution process of the ransomware mentioned above, before 2.2 in Fig. 2 is the pre-encryption stage. The ransomware will involve a large number of API calls during the pre-encryption stage, including file read and write, network communication, system information acquisition, etc. The number of APIs that normal software runs during the same time period is much smaller than the number of APIs called by ransomware. Therefore, this article believes that the number of APIs executed by software within a period of time after it starts running can be used to distinguish between normal software and ransomware.

In this module, REDDS will collect the API sequences called during the pre-encryption phase after the ransomware

starts running, as well as the API sequences of the benign software, and use them as inputs for the next phase. Run samples of ransomware and benign software in the CuCKoo sandbox or other sandbox, with a running time of 60 seconds to ensure that the API sequence of ransomware can be fully captured during the pre-encryption phase. And use API Monitor to monitor the API sequence of these software, record the API sequence of each ransomware before the first call to the encryption class API and the API sequence of benign software.
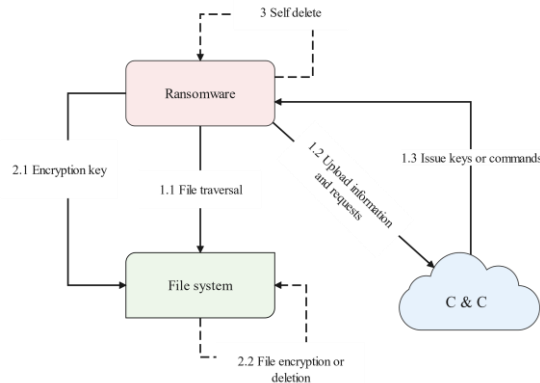


Fig. 2. General execution process of ransomware file traversal and encryption stages.

TABLE I. API CALLED FOR THE FIRST TIME IN BCRYPT, DPAPI, NCRYPT, SCHANNEL, AND WINCRYPT ENCRYPTION API LIBRARIES

| Cryptographic API libraries | API |
|---|---|
| BCrypt | BCryptOpenAlgorithmProvider |
| CryptoAPI | cryptAcquireContext, cryptBinary |
| DPAPI | CryptProtectData |
| Ncrypt | NCryptOpenStorageProvider |
| Schannel | AcquireCredentialsHandle |

Ransomware typically utilizes the encryption API provided by the Windows system to implement file encryption and decryption functions. The Windows system provides multiple encryption API libraries, and attackers can choose the appropriate encryption API library to implement encryption functions according to their own needs. There are five commonly used encryption API libraries: BCrypt, CryptoAPI, DPAPI, Ncrypt, and Schannel. These five encryption API libraries have different functions to implement various functions. The first called APIs in the five encryption API libraries are shown in Table I. REDDS takes these APIs as the pre-encryption boundaries and collects the API sequences in the pre-encryption stage. The collected API sequences are deduplicated, and the deduplicated API sequences are used as data sets for subsequent analysis and research.

*B. API Sequence Feature Calculation*

In this stage, REDDS uses the n-gram algorithm to segment API sequences and calculates corresponding eigenvalues using the TF-IDF algorithm. The application of the n-gram algorithm preserves the adjacency of APIs in the generated feature vectors. After processing API sequences

through n-gram algorithm, TF-IDF algorithm in natural language processing is used to calculate eigenvalues to generate eigenvectors. Use (1) to calculate the TF value of the n-gram sequence for ransomware and normal software.

$$TF(i,j) = \frac{n(i,j)}{\sum_k n(k,j)} \qquad (1)$$

Where $TF(i,j)$ represents the frequency of n-gram $i$ appearing in n-gram sequence $j$, where $n(i,j)$ represents the number of times n-gram $i$ appears in n-gram sequence $j$, $\sum_k n(k,j)$ represents the total number of n-grams in the n-gram sequence $j$. After calculating the frequency of an n-gram, calculate its IDF using equation (2).

$$IDF(i) = log_2 \frac{|D|}{|\{j:i\in j | j \in D\}|} \qquad (2)$$

Among them, $IDF(i)$ describes the rarity of n-gram $i$ in the entire n-gram sequence, and $D$ represents the set of all n-gram sequences. $\{j: i \in j | j \in D\}$ represents the number of n-gram sequences $j$ containing n-gram $i$. After calculating the $IDF(i)$, use equation (3) to complete the calculation of TF-IDF.

$$TF_{IDF(i,j)} = TF(i,j) \times IDF(i) \qquad (3)$$

In summary, REDDS treats the API sequences collected in the pre-encryption stage of ransomware as a whole, and obtains the corresponding feature vectors through n-gram and TF-IDF algorithms.

*C. Data Enhancement and Detection Based on WGAN-GP*

The dynamically collected API sequences are limited and incomplete, which will affect the detection of ransomware variants and unknown ransomware. To this end, we propose a data enhancement algorithm based on WGAN-GP, which satisfies the Lipschitz restriction by applying an independent gradient penalty (GP) to each sample. This allows the weights of neurons to be distributed more evenly during the backpropagation process, helping the detection model to better understand the potential characteristics and behaviors of ransomware, effectively improving the accuracy, robustness and generalization ability of the ransomware detection model.

The API sequence data enhancement method based on WGAN-GP introduces Wasserstein distance on the basis of GAN model, and its distance formula is shown in equation (4).

$$W(P_r, P_f) = \inf_{\gamma \in \Pi(P_r,P_f)} E_{(x,y)\sim\gamma} [||x - y||] \quad (4)$$

In the formula: $x$ is the real sample, and $y$ is the generated sample. $\prod(P_r, P_f)$ is the joint probability distribution set of the real sample probability distribution $P_r$ and the generated sample probability distribution $P_f$.

The use of Lipschitz weight pruning in WGAN limits the range of weight parameters in the discriminator sub network, resulting in extreme network parameters that greatly limit network performance and weaken the fitting ability of the neural network. Moreover, the scope of weight pruning is mainly based on expert experience, and setting network parameters through manual determination can easily lead to inappropriate parameter settings, leading to the phenomenon of gradient explosion and vanishing again. Therefore, WGAN-

GP introduces the Gradient Penalty (GP) term to improve the impact of the weight clipping constraint parameter used in WGAN to meet the 1-Lipschitz continuity condition on the network. Its loss function is expressed as follows:

$$L_G = -E_{z \sim P_z} \times [D(G(Z))] \quad (5)$$

$$L_D = -E_{z \sim P_z} \times [D(G(Z))] - E_{z \sim P_z} \times [D(x)] + GP \quad (6)$$

$$GP = \lambda E_{x \sim \chi}\left[||\nabla D(x)||_p - 1\right]^2 \quad (7)$$

In the formula: $L_G$ is the generator loss function, $L_D$ is the discriminator loss function, $G(Z)$ is the sample generated by the generator, $P_z$ is a prior distribution of random noise $z$. $GP$ is a gradient penalty term, $\lambda$ Represents the penalty coefficient; $\chi$ represents the distribution of the entire sample space, that is, the sum of the generated and real sample distributions; $\nabla D(x)$ represents the gradient of the discriminator, and $||\cdot||_p$ is the P-norm.
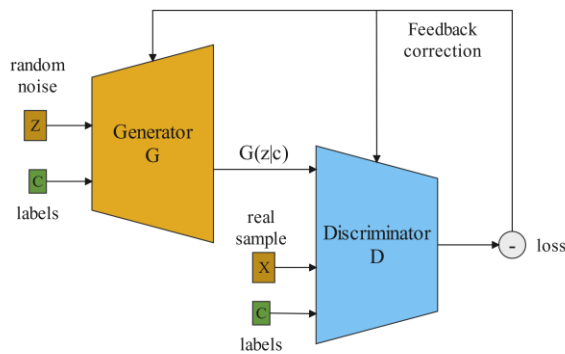


Fig. 3. Schematic diagram of WGAN-GP structure.

The schematic diagram of WGAN-GP structure is shown in Fig. 3. Through continuous training of the WGAN-GP network, the data obtained by the generator is closer to real data, but the final discriminator cannot recognize whether the input data comes from actual data or generated data, thus achieving Nash equilibrium and forming a good generation model [26].

The specific training process for data augmentation and detection based on WGAN-GP is as follows:

*1) Input* the feature vectors obtained from feature calculation into the generator;

*2) Fix* the parameters of generator G, and adjust the parameters of generator according to formula (5) to minimize the loss function of generator $L_G$;

*3) Fix* the parameters of generator D, and adjust the parameters of discriminator according to formula (6) to minimize the discriminator loss function $L_D$;

*4) Cycle* through the above two steps until the training network achieves Nash equilibrium, and then stop training.

*5) Expand* the original collected API sequence using WGAN-GP and train the detection model to detect ransomware.

## IV. RDCO ONTOLOGY CONSTRUCTION AND DEFENSE COUNTERMEASURE REASONING

Starting from the API called by the ransomware, we map some specific malicious APIs to ATT&CK technology. Based on the work of integrating multi-source security knowledge [21], malicious APIs and multi-source security knowledge are mapped. However, the link between ransomware and defense countermeasures is implicit. Ontology can discover new relationships from known knowledge through the formal description of knowledge in a specific domain, and the design of reasoning rules based on the ontology. Therefore, this paper proposes a defense countermeasure reasoning method for ransomware based on semantic ontology and rule logic, and infers corresponding defense countermeasures for the APIs called in the ransomware.

### A. Ransomware API mapping Multi-source Security Knowledge

The existing ransomware that can infect Windows systems is operated by calling a large number of Windows APIs. By analyzing the attack process of ransomware and the technologies under the Windows platform in enterprise ATT&CK, some common APIs are mapped to corresponding technologies in the ATT&CK framework. For example, the widely used defense avoidance technique in ransomware - process injection, which runs custom code in the address space of another process. Process injection improves invisibility, and some technologies also achieve persistence [27]. There are many types of process injection techniques. This example analyzes the classic malicious dynamic link library (DLL) injection technique, and its corresponding ATT&CK technique is T1055.001. The injection process of DLL is shown in Fig. 4, where the ransomware calls VirtualAllocEx to obtain a space to write the path to its DLL. Then, ① call WriteProcessMemory to write the path to the allocated memory. In order for the code to execute in another process, ② will call APIs such as CreateRemoteThread, NtCreateThreadEx, or RtlCreateUserThread. Finally, ③ successfully injected the ransomware code into the target process.
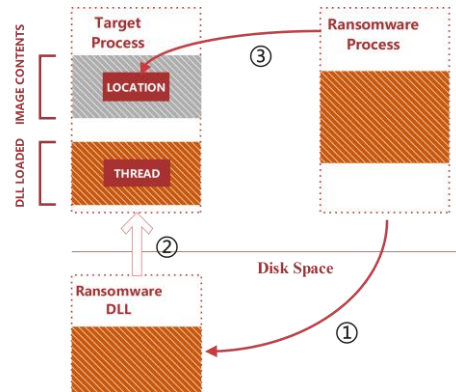


Fig. 4. Ransomware creates remote threads and loads libraries for classic DLL injection.

Through the above analysis, the T1055.001 technology can be mapped to the API during the DLL injection process. Map 47 technologies with their corresponding APIs based on the

data components (operating system API execution) in the ATT&CK framework. At the same time, CAPEC focuses on the attack pattern, linking the tactics and techniques in ATT&CK with the weakness of the attack target, and using the weaknesses in CWE to link to vulnerabilities in CVE. And integrate defense technology in D3FEND through digital artifacts. Fig. 5 depicts the relationship links mapped according to the selected knowledge sources. Through this end-to-end link method, security researchers can not only analyze potential threats to the system, but also defend against ransomware attacks based on defense strategies.
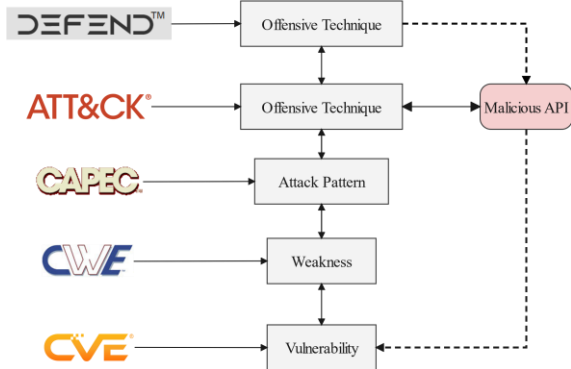


Fig. 5. Schematic diagram of security knowledge relationship mapping link.

### B. Build Ontology and Design Inference Rules

Based on the mapping between security knowledge and malicious APIs of ransomware, a Ransomware Defensive Countermeasures Ontology (RDCO) is proposed. The ontology model consists of classes, attributes, and relationships between classes and individuals [28]. RDCO includes seven categories: ransomware behavior, offensive techniques, digital artifacts, defensive countermeasures, attack patterns, weaknesses, and vulnerabilities. Classes and the relationships between classes are shown in Fig. 6.
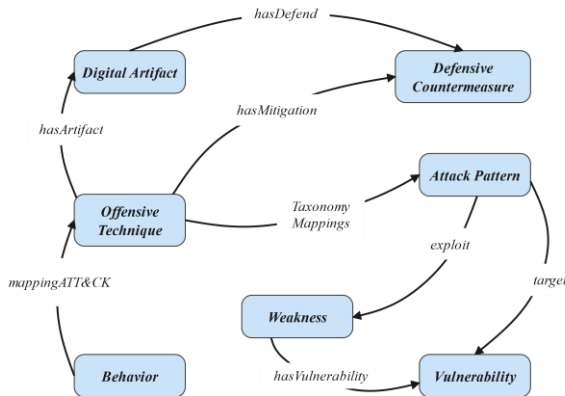


Fig. 6. Relationship between RDCO top-level classes.

In order to better infer defense countermeasures and vulnerabilities from the RDCO ontology, this paper uses the semantic inference rule description language recommended by W3C to design inference rules for SWRL (semantic web rule language) [29]. To implement SWRL rules in an ontology, it is necessary to write and describe the reasoning conditions (Antecedent) and the reasoning results (Consequence) in

language. A single or multiple basic atoms (which are already knowledge constructed in the ontology) form each SWRL rule in the reasoning, and represent it as a logical "AND" relationship through "^". The connection between the reasoning conditions and results is made through "→", Create rules for expanding existing OWL languages, where the formal expression of SWRL rules is:

$$(\wedge_{i=1}^{m} A_i) \rightarrow (\wedge_{j=1}^{n} B_j), m \geq 1, n \geq 1 \qquad (8)$$

Equation (8) $A_i$, $B_j$ is a fundamental atom, and their form can be represented as C (x), P (x, y), or (x, y), where C is an OWL description, P is an OWL attribute, and x and y can be OWL instances or OWL data values. Only when atoms have been constructed in the ontology and are all true can SWRL rules be effectively set. Using SWRL rules, new relationships can be discovered from known knowledge. As shown in Table II, we designed three inference rules based on RDCO ontology to infer relevant defense strategies for ransomware.

TABLE II.    INFERENCE RULE TABLE

| Order | Inference rule |
|---|---|
| $R_1$ | *Behavior(?b)^mappingAttack(?b, ?t)^Offensive_Technique(?t)^TaxonomyMappings(?t, ?a)^Attack_Pattern(?a)^exploit(?a, ?w)^Weakness(?w)^hasVulnerability(?w, ?v) ->exploitVulnerbility(?b, ?v)* |
| $R_2$ | *Behavior(?b)^mappingAttack(?b,?t)^Offensive_Technique(?t)^hasMitigation(?t,?m) ->useMitigation(?b, ?m)* |
| $R_3$ | *Behavior(?b)^mappingAttack(?b,?t)^Offensive_Technique(?t)^hasArtifact(?t,?da)^Digital_Artifact(?da)^hasDefend(?da,?dt)^defensive_technique(?dt)->useDefendTechniques(?b, ?dt)* |

Rule $R_1$: Using the attack pattern that CAPEC focuses on as a bridge, associate the attack technology used by the attacker with the weaknesses of the attack target. Due to the fact that weakness in CWE can be linked to vulnerabilities in CVE, it is possible to infer vulnerabilities exploited by ransomware. Knowing the exploited vulnerabilities can help to promptly fix them and prevent ransomware attacks.

Rule $R_2$: When the malicious API of ransomware is known, by mapping the API to ATT&CK technology, each ATT&CK technology in the ATT&CK framework has its corresponding mitigation measures, thereby automatically extracting mitigation measures related to ransomware.

Rule $R_3$: In addition to inferring mitigation measures in response to ransomware attacks, the API of ransomware is mapped to ATT&CK technology, using digital artifacts as a medium to automatically infer defense technologies in D3FEND corresponding to ransomware in response to ransomware attacks

## V. EXPERIMENTS AND EVALUATION

### A. Experimental Dataset

There is currently no publicly available ransomware standard dataset in the academic community. This article builds a Cuckoo sandbox, in which the Windows 7 operating system is used as the software runtime environment. Run the sample for 60 seconds and collect the API sequence called during software runtime. The ransomware samples used in the

experiment were collected from Virusshare and Any. Run, and the normal samples were collected from 360 software stewards. See Table III for the types and quantities of the experimental samples. The versions of different samples in the same ransomware sample family are different. The normal software covers antivirus software, office software, chat tools, download tools, video software, browsers, input methods and other common types.

This article truncates the collected API sequences and only studies the API sequences before encrypting them. After analysis, it was found that a file operation of ransomware often requires calling four APIs, such as CreatFile, WriteFile, HWrite, LClose, etc., to quickly create a file. Therefore, REDDS uses the 4-gram algorithm in feature calculation, and then calculates the eigenvalues through TF-IDF, which can make the generated feature vectors best match the features of the API sequence.

TABLE III.    TYPES AND QUANTITY OF EXPERIMENTAL SAMPLES

| Ransomware family | N | Ransomware family | N | Ransomware family | N | Normal software samples | N |
|---|---|---|---|---|---|---|---|
| Alphacrypt | 4 | Prolock | 2 | Maze | 3 | Browser | 2 |
| Cerber | 4 | Ransomware.Dharma | 5 | SATURN | 2 | Chat Tools | 2 |
| CryptoWire | 2 | Ransomware.Eleta | 2 | SilentSpring | 1 | Download Tools | 4 |
| Crysis | 8 | Ransomware.FRS | 3 | PolyRansom | 4 | Inputting Method | 3 |
| Gandcrab | 6 | Ransom.LockerGoga | 4 | Spora | 4 | Video software | 5 |
| Lockbit | 2 | Ransomware.Kraken | 5 | Sodinokibi | 6 | Safe Antivirus | 2 |
| CryptoShield | 2 | Ransomware.Wlu | 2 | Teslacrypt | 5 | Office-Software | 16 |
| Mzrevenge | 4 | Ransomware.SAGE | 2 | Wannacry | 4 | Other | 6 |
| Total number of ransomware samples | 86 | | | | | Total number of normal samples | 40 |

### B. Evaluation of WGAN-GP Model Generation Capability
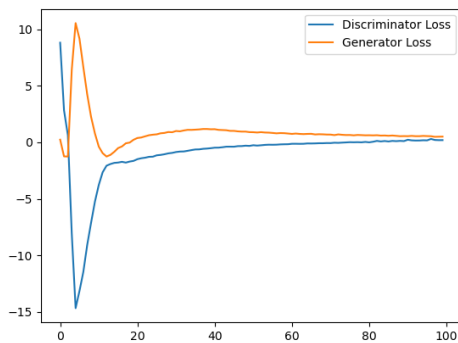


Fig. 7.    Curve of loss function.

After repeated debugging, it is determined that the discriminator uses a three-layer neural network structure, and each layer is followed by a hyperbolic tangent activation function (Tanh). The generator adopts a 4-layer neural network structure, and ReLu activation function is used behind each layer. The optimization solver uses Adam, the learning rate of the generator and discriminator is set to 0.0005, and the training round is 10000. The loss function curve of generator and discriminator during training is shown in Fig. 7. The API sequence data enhancement method based on WGAN-GP is used to enhance the API sequence of ransomware and the API sequence of normal software respectively. The API sample library before and after augmentation is shown in Table IV.

TABLE IV.    API SAMPLE LIBRARY BEFORE AND AFTER DATA AUGMENTATION

| Type | Before data enhancement | After data enhancement |
|---|---|---|
| Ransomware samples | 86 | 1634 |
| Normal samples | 40 | 1218 |

The authenticity, probability fitting accuracy, and diversity of generated samples are important indicators for evaluating the generation ability of a model. This paper includes two generative model, BEGAN (boundary equilibrium GAN) [30] and LSGAN (Least Squares GAN) [31], as reference objects to evaluate the generation capability of WGAN-GP model.



(a) WGAN-GP generates samples.

(b) LSGAN generates samples.

(c) BEGAN generates samples.
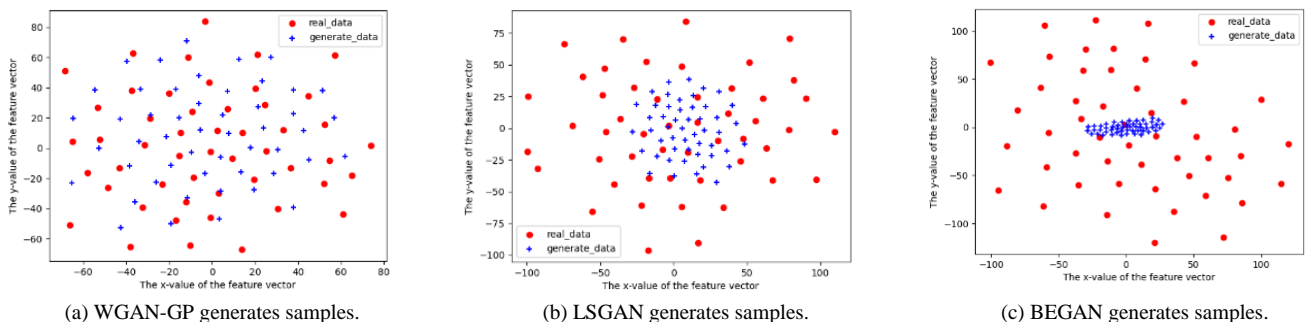
Fig. 8.    API sequence generation sample dimensionality reduction visualization for ransomware.

Taking the API sequence samples of ransomware generated by WGAN-GP, BEGAN, and LSGAN models as examples, t-distributed stochastic neighbor embedding (t-SNE) algorithm is used to perform dimensionality reduction analysis on real samples and partially generated samples of each model. The visualization results are shown in Fig. 8. From Fig. 8, it can be clearly seen that the samples generated by the BEGAN and LSGAN models are concentrated within a small range near the real sample, while WGAN-GP, due to considering the 1-Lipschitz condition limitation, generates scattered samples within the real sample distribution range, with good diversity.

Kernel Perception Distance (KID) is used to evaluate the authenticity of the generated samples, and KID uses Gaussian kernel functions to measure the similarity between the real dataset and the generated dataset in the Perception feature space. The KID values of the samples generated by the three GAN models are shown in Table V. It is evident from Table V that the KID values of the WGAN-GP generated samples are significantly lower than those of the LSGAN and BEGAN models. The smaller the KID value, the closer the generated sample is to the real sample.

TABLE V.    KID VALUES OF SAMPLES GENERATED BY THREE GAN MODELS

| Type | Ransomware | Normal software | Average value |
|---|---|---|---|
| WGAN-GP | $5.702\times 10^{-6}$ | $4.171\times 10^{-6}$ | $4.935\times 10^{-6}$ |
| LSGAN | 1.998 | 1.878 | 1.938 |
| BEGAN | 1.295 | 1.207 | 1.251 |

*C. Detection Model*

The expanded API sequence dataset was divided into a training set and a testing set in a ratio of 70% to 30%. The detection performance of five classification algorithms, namely Support Vector Machine (SVM) [32], RF [32], Naive Bayes (NB) [32], K-Nearest Neighbor (KNN) [33], and MLP [34], was further compared before and after using WGAN-GP data augmentation.

This article uses commonly used accuracy, precision, recall, and F1 score (F1) in the field of malware detection as performance evaluation indicators [35].

TABLE VI.    THE P, R, AND F1 VALUES OF THE FIVE DETECTION MODELS BEFORE AND AFTER USING WGAN-GP

| | Before using WGAN-GP | | | After using WGAN-GP | | |
|---|---|---|---|---|---|---|
| | P | R | F1 | P | R | F1 |
| SVM | 0.884 | 0.875 | 0.877 | 0.941 | 0.904 | 0.913 |
| NB | 0.876 | 0.873 | 0.878 | 0.940 | 0.904 | 0.912 |
| KNN | 0.883 | 0.857 | 0.872 | 0.968 | 0.964 | 0.965 |
| RF | 0.958 | 0.961 | 0.959 | 0.996 | 0.994 | 0.995 |
| MLP | 0.873 | 0.884 | 0.865 | 0.994 | 0.992 | 0.993 |
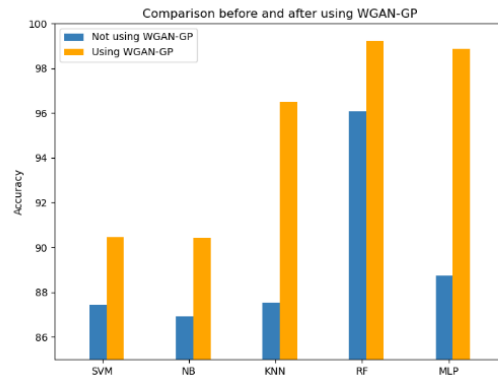


Fig. 9.    Comparison of accuracy of detection models before and after data enhancement.

Fig. 9 shows the accuracy of the detection models before and after using WGAN-GP data augmentation. It can be seen that the accuracy of all five detection models has increased after using data augmentation. Among them, MLP's accuracy rate increased the most, by 10.12%. RF has the highest accuracy, reaching 99.23% after data enhancement. Table VI shows the P, R, and F1 values of the five detection models before and after using WGAN-GP data augmentation. From the results in Table VI, it can be seen that among the five classification algorithms used in this article, the detection results obtained using RF and MLP are superior to the other three algorithms. The experimental results indicate that using WGAN-GP data augmentation can significantly improve the performance of the target detection model. By using WGAN-GP data augmentation, we can utilize more data to train and optimize the model, thereby improving its accuracy and robustness.

*D. Defense Countermeasure Reasoning*

HermiT general rule inference engine is used to describe the proposed inference rule set, and it is integrated in the RDCO ontology model. The model is based on the security domain knowledge base and the condition pattern in the reasoning rule set for reasoning. Ransomware often exploits system or software security vulnerabilities to gain system privileges and install ransomware on the victim's computer. Finding and fixing these vulnerabilities can help us better defend against ransomware attacks.

After detecting the ransomware, the inference engine passes the inference rule $R_1$ Infer the associated security vulnerabilities based on the behavior of specific ransomware. Taking the API of ransomware calling ChangeServiceConfigW and CreatServiceW as an example, new implicit facts are inferred according to the rules. The inference engine associates the specific API of ransomware with the security vulnerabilities that may be exploited in the system through the object attribute exploitVulnerability. To clearly display the specific reasoning results, Neo4j is used to visualize them in the form of a knowledge graph. As shown in Fig. 10, the yellow arrow in the figure represents the inferred relationship exploitVulnerability.

Fig. 10. Security vulnerability reasoning results.

Map specific APIs called by ransomware to ATT&CK technology, and each ATT&CK technology has corresponding mitigation and defense measures. By inference rule $R_2$ and $R_3$ can automatically infer defense strategies targeting specific APIs, helping security managers respond to ransomware attacks and deploy appropriate security solutions. Taking the APIs called by the aforementioned ransomware, ChangeServiceConfigW and CreatServiceW, as examples, the specific APIs of the ransomware are associated with mitigation measures and defense technologies through the object properties useMigration and useDefendTechniques. The specific reasoning results are shown in Fig. 11, where the orange and red arrows represent the inferred relationships useMitigation and useDefendTechniques, respectively.
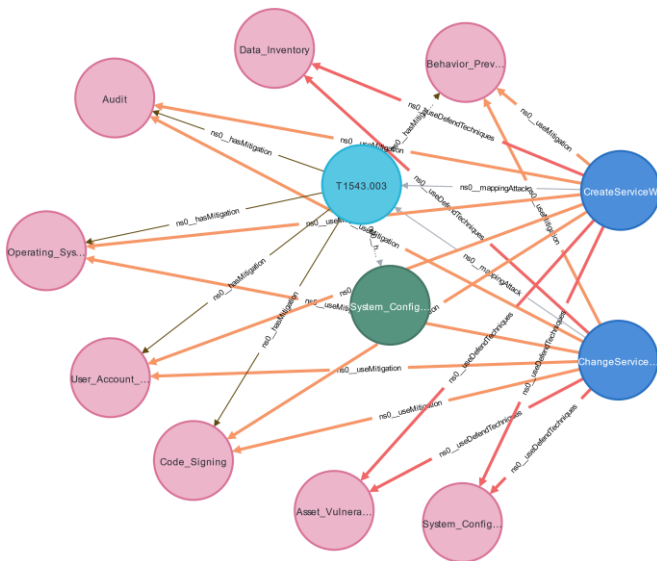


Fig. 11. Defense strategy reasoning results.

## VI. CONCLUSION

This article proposes an early detection and defense system for ransomware based on API sequences. To address the limitations of collecting datasets, API sequences were enhanced based on Wasserstein GAN with Gradient Penalty (WGAN GP), and then machine learning classification algorithms were used to train the enhanced data to detect ransomware. The detection accuracy was significantly improved after using WGAN-GP data augmentation, with the RF algorithm having the highest accuracy of 99.23%. By mapping the malicious APIs of ransomware to public security knowledge bases such as ATT&CK, a Ransomware Defense Countermeasures Ontology (RDCO) is proposed. Based on the ontology model, a set of inference rules are designed, and corresponding defense Countermeasures are automatically inferred based on the malicious APIs in ransomware, helping security managers respond to ransomware attacks and deploy appropriate security solutions. In the follow-up work, we will be committed to the detection and defense of ransomware attacks in the field of industrial internet of things.

## REFERENCES

[1] Alqahtani A, Sheldon F T. A survey of crypto ransomware attack detection methodologies: an evolving outlook[J]. Sensors, 2022, 22(5): 1837.

[2] Al-rimy B A S, Maarof M A, Shaid S Z M. Ransomware threat success factors, taxonomy, and countermeasures: A survey and research directions[J]. Computers & Security, 2018, 74: 144-166.

[3] Chen Changqing, Guo Chun, Cui Yunhe, Shen Guowei, Jiang Chaohui. An early detection method for ransomware based on API short sequences [J]. Journal of Electronics, 2021,49 (03): 586-595.

[4] Connolly L Y, Wall D S. The rise of crypto-ransomware in a changing cybercrime landscape: Taxonomising countermeasures[J]. Computers & Security, 2019, 87: 101568.

[5] Kok S H, Abdullah A, Jhanjhi N Z, et al. Prevention of crypto-ransomware using a pre-encryption detection algorithm[J]. Computers, 2019, 8(4): 79.

[6] Tang F, Ma B, Li J, et al. RansomSpector: An introspection-based approach to detect crypto ransomware[J]. Computers & Security, 2020, 97: 101997.

[7] Umar R, Riadi I, Kusuma R S. Analysis of conti ransomware attack on computer network with live forensic method[J]. IJID (International Journal on Informatics for Development), 2021, 10(1): 53-61..

[8] Hayes K. Ransomware: a growing geopolitical threat[J]. Network Security, 2021, 2021(8): 11-13.

[9] Kok S, Abdullah A, Jhanjhi N, et al. Ransomware, threat and detection techniques: A review[J]. Int. J. Comput. Sci. Netw. Secur, 2019, 19(2): 136.

[10] Gulrajani I, Ahmed F, Arjovsky M, et al. Improved training of wasserstein gans[J]. Advances in neural information processing systems, 2017, 30.

[11] REN Zhuojun,CHEN Guang,LU Wenke. Malicious code visualization method based on N_gram features[J].Acta Electronic Sinica,2019,47(10):2108-2115.)

[12] Zhang W, Yoshida T, Tang X. A comparative study of TF* IDF, LSI and multi-words for text classification[J]. Expert systems with applications, 2011, 38(3): 2758-2765.

[13] Morato D, Berrueta E, Magaña E, et al. Ransomware early detection by the analysis of file sharing traffic[J]. Journal of Network and Computer Applications, 2018, 124: 14-32.

[14] Al-Rimy B A S, Maarof M A, Alazab M, et al. Redundancy coefficient gradual up-weighting-based mutual information feature selection

technique for crypto-ransomware early detection[J]. Future Generation Computer Systems, 2021, 115: 641-658.

[15] Mehnaz S, Mudgerikar A, Bertino E. Rwguard: A real-time detection system against cryptographic ransomware[C]//Research in Attacks, Intrusions, and Defenses: 21st International Symposium, RAID 2018, Heraklion, Crete, Greece, September 10-12, 2018, Proceedings. Cham: Springer International Publishing, 2018: 114-136.

[16] Roy K C, Chen Q. DeepRan: Attention-based BiLSTM and CRF for ransomware early detection and classification[J]. Information Systems Frontiers, 2021, 23: 299-315.

[17] Liu X, Li T, Zhang R, et al. A GAN and feature selection-based oversampling technique for intrusion detection[J]. Security and communication networks, 2021, 2021: 1-15.

[18] Hu W, Tan Y. Generating adversarial malware examples for black-box attacks based on GAN[C]//Data Mining and Big Data: 7th International Conference, DMBD 2022, Beijing, China, November 21–24, 2022, Proceedings, Part II. Singapore: Springer Nature Singapore, 2023: 409-423.

[19] Khammassi C, Krichen S. A GA-LR wrapper approach for feature selection in network intrusion detection[J]. computers & security, 2017, 70: 255-277.

[20] Wu Yangming, Zong Xuejun, He Kan. DBN-ELM intrusion detection method based on data augmentation [J]. Science and Technology and Engineering, 2022,22 (34): 15195-15202.

[21] Zhang S, Bai G, Li H, et al. Multi-source knowledge reasoning for data-driven IoT security[J]. Sensors, 2021, 21(22): 7579.

[22] Han W, Xue J, Wang Y, et al. APTMalInsight: Identify and cognize APT malware based on system call information and ontology knowledge framework[J]. Information Sciences, 2021, 546: 633-664.

[23] Rastogi N, Dutta S, Zaki M J, et al. Malont: An ontology for malware threat intelligence[C]//Deployable Machine Learning for Security Defense: First International Workshop, MLHat 2020, San Diego, CA, USA, August 24, 2020, Proceedings 1. Springer International Publishing, 2020: 28-44.

[24] Ding Y, Wu R, Zhang X. Ontology-based knowledge representation for malware individuals and families[J]. Computers & Security, 2019, 87: 101574.

[25] Liu Wenjing, Guo Chun, Shen Guowei, Xie Bo, Lv Xiaodan. A deep learning based early detection method for ransomware [J]. Computer Science, 2023,50 (03): 391-398.

[26] Hu M, He M, Su W, et al. A TextCNN and WGAN-gp based deep learning frame for unpaired text style transfer in multimedia services[J]. Multimedia Systems, 2021, 27: 723-732.

[27] Hosseini, A. (2017, July 18). Ten Process Injection Techniques: A Technical Survey Of Common And Trending Process Injection Techniques. Retrieved December 7, 2017.

[28] Grégio André, Bonacin Rodrigo, Marchi Antonio Carlos de, Nabuco Olga Fernanda, Geus Paulo Lício de. An ontology of suspicious software behavior. Applied Ontology, (11) (2016) 29–49 https://doi.org/10.3233/AO-160163.

[29] Horrocks I, Patel-Schneider P F, Boley H, et al. SWRL: A semantic web rule language combining OWL and RuleML [S/OL]. World Wide Web Consortium (W3C), 2004 http://www.daml.org/rules/proposal/

[30] Berthelot D, Schumm T, Metz L. Began: Boundary equilibrium generative adversarial networks[J]. arXiv preprint arXiv:1703.10717, 2017.

[31] Mao X, Li Q, Xie H, et al. Least squares generative adversarial networks[C]//Proceedings of the IEEE international conference on computer vision. 2017: 2794-2802.

[32] Harrington P. Machine learning in action[M]. Simon and Schuster, 2012.

[33] Singh K, Agrawal S. Comparative analysis of five machine learning algorithms for IP traffic classification[C]//2011 International conference on emerging trends in networks and computer communications (ETNCC). IEEE, 2011: 33-38.

[34] Singh K, Agrawal S. Comparative analysis of five machine learning algorithms for IP traffic classification[C]//2011 International conference on emerging trends in networks and computer communications (ETNCC). IEEE, 2011: 33-38.

[35] Sharma S, Singh S. Texture-Based Automated Classification of Ransomware[J]. Journal of The Institution of Engineers (India): Series B, 2021, 102: 131-142.

# The Holistic Expression Factors of Emotional Motion for Non-humanoid Robots

Qisi Xie, Ding-Bang Luh*

School of Art and Design, Guangdong University of Technology, Guangzhou 510006, China

*Abstract*—**The development of technology and the increasing prevalence of solitary living have transformed non-humanoid robots, such as robotic sweepers and mechanical pets, into potential sources of emotional support for individuals. Nevertheless, the majority of non-humanoid robots currently in existence are task-oriented and lack features such as facial expressions and sound. Existing research primarily emphasizes the details of human motion in robot motion design, while devoting less attention to the analysis of universal emotional expression factors and methods rooted in human recognition patterns. In our initial step, a theoretical framework and holistic expression factors were proposed based on Gestalt theory and SOR theory. These factors encompass vertical and horizontal motion direction, stimulation, and vertical repetition. Subsequently, animation simulation tests were conducted to confirm and examine the contributions of each factor to the recognition of emotional expressions. The results indicate that both vertical and horizontal movements can convey emotional valence. However, if both of them exist, there is no leading direction to the valence recognition result. When both vertical and horizontal movements are present, valence recognition is influenced by the combined effects of stimulation, vertical repetition, and movement direction. Simultaneously, non-humanoid robots can display recognizable emotional content when influenced by holistic expression factors. This framework can serve as a universal guide for emotional expression tasks in non-humanoid robots, proving the hypothesis that Gestalt theory is applicable in dynamic emotional recognition tasks. At the same time, these findings propose a new holistic perspective for designing emotional expression methods for robots.**

*Keywords—Human-robot interaction; robot emotion; non-humanoid robot; movement*

## I. INTRODUCTION

Due to evolving societal trends like the stay-at-home economy, the single economy, and an aging population, robots are poised to become indispensable companions for humans. These robots offer not only functional services but also emotional support to humans. Currently, non-humanoid robots are increasingly integrated into human life as the most ubiquitous non-human characters. For instance, everyday household items like robotic sweepers [1], interactive pets such as Cozmo [2] and BB-8 [3], the chicken-shaped Keepon [4] and seal-shaped PARO [5] used in hospitals for patient recovery, robot dogs that can assist in search and rescue, as well as drones used for large-scale performances [6] are all becoming increasingly prevalent. It is foreseeable that more non-humanoid robots will play a more significant and pervasive role in human life in the future [7]. However, these non-humanoid robots exhibit significant differences in appearance compared to humans, posing challenges in expressing emotions through human-like behavior imitation. Furthermore, many task-focused non-humanoid robots lack essential components like facial expressions and auditory capabilities [1]. Therefore, designing emotional motion expressions for non-humanoid robots that can effectively convey understandable emotional states to humans has become a crucial research topic.

The three primary categories of currently conducted research on emotional motion expression in robots are artificial design, artistic theory guiding, and emotional computing.

Firstly, artificial design based on robot features through the simulation of localized human body movements is the most widely used method in current research for expressing robot emotions and behaviors. For instance, robots were programmed to convey positive emotions through human-like gestures [8], such as cheering, applauding, and wave dancing for positive emotion, while negative emotions were represented using gestures like shrugging and crossing the arms. Similarly, Valenti et al. employed the Nao [9] robot to devise gestures based on human arm movements for expressing basic emotions. Johnson and Cuijpers conducted network experiments to investigate changes in the head position of robots, and found that people expect robots to lower their heads and gaze downward when expressing anger, sadness, fear, or disgust [10]. Moreover, Shimi [11] is a camera whose movements are expressed through artificially designed body postures. Keepon [4], designed with a biological appearance, enhanced emotional expression through gaze and body movements by manual design. The effectiveness of such expression relies on the resemblance between the robot and the human body, making it challenging to apply these results to the motion design of other robots.

Secondly, art theories have contributed methods for robotic expressions. The primary representative theories include animation theory [12] and dance theory. Animation theory relies on the 12 principles of animation to imbue robot motion with a realistic sense of life, such as helping drones convey intentions through path and speed during flight [13], and assisting robots in displaying behavior comprehensible to users [14]. Nevertheless, due to inherent limitations in robot flexibility, degrees of freedom, and movement speed, animation methods can hardly be fully utilized to convey robot emotional expressions. The Laban system [15] was originally used in dance research to describe the quality of motion. For example, Burton et al. [16] proposed to find emotionally similar movements from the database by using the Laban system and incorporating expressive content into a specific

robot motion trajectory. However, when applying this system to robot research, it is necessary to identify suitable emotional expression elements tailored to each robot's unique characteristics. The selection varies based on individual characteristics and cannot be universally applied. Consequently, the application of art theories is limited to robots with specific attributes, and the absence of these detailed elements may limit the range of emotional expression capabilities.

Thirdly, emotional computing has emerged as a prevalent method in robot motion design. Leveraging advanced computer technology, machine learning algorithms extract relevant features from extensive labeled exemplar data, allowing the system to automatically generate expression trajectories. Common methods include principal component analysis (PCA) [17], factored conditional restricted Boltzmann machines (FCRBMs) [18], factored Gaussian process dynamic models (GPDM) [19], and neural network methods [20, 21], etc. Machine learning methods rely on human motion data, such as motion capture or large corpora. However, their generalization ability and scalability are limited. Even when using the same database, if the images used for training and testing are not the same or differ significantly, the final results will also be different. Therefore, machine learning approaches often exhibit relatively simplistic outcomes [22]. The majority of works still focus on single tasks such as walking, and typically involving specific structures [23], with humanoid structures being the most prevalent. Therefore, machine learning methods are limited to single objects with the same features.

In summary, current research on robot emotional expression primarily concentrates on specific or localized expressions. Consequently, these outcomes exhibit variations among individuals and lack generalizability, hindering the assurance of consistent expression results. Moreover, pertinent studies have yet to analyze the key factors influencing users' recognition of emotional expressions from the perspective of overall motion states.

Building upon the preceding discussion, this article poses a question grounded in the Gestalt effect: Is human recognition of emotional movement expression also influenced by their perception of the entire motion? Is it possible to convey emotion through the presentation of holistic expression factors?

This article aims to analyze the expression factors that affect users' emotional recognition of robots from a holistic perspective and help reduce the burden of communication on users during interactions with different non-humanoid robots. Consequently, it can facilitate rapid user acceptance of robots and foster the growth of related markets. At the same time, this research offers a novel perspective for designing emotional expression methods in robots by investigating recognition rules for emotional expression, which helps simplify the expression design of non-humanoid robots.

In our study, we initially established an experimental theoretical framework based on Gestalt theory and SOR theory, and then we derived a comprehensive set of expression factors, including vertical and horizontal motion directions, stimulation, and vertical repetitive motion. Subsequently, we explored the pivotal role played by movement direction and

developed hypotheses grounded in approach-withdrawal theory and embodied emotion theory. Detailed information on this section is provided in Section II.

Then, Section III primarily focused on the effect of motion direction as the main factor on valence expression, which related to $H_1$. Section IV was dedicated to resolving and validating $H_2$ and $H_3$, which focused on analyzing the collective effects of all the holistic factors on emotional expression. Section V encompassed a comprehensive discussion of our findings, while Section VI offered a summary of the study's key outcomes.

## II. CONCEPTUAL MODEL AND HYPOTHESES DEVELOPMENT

Gestalt psychology [24] points out that people's perception towards objective objects are rooted in holistic relationships rather than specific elements. They emphasizes that the whole of anything is greater than its parts. Based this concept, we bring up the question: does human recognition of robot emotional actions also come from their perception of overall motion?

In addressing this question, we began by extracting holistic factors from Gestalt theory to analyze emotional expression. In Gestalt theory, holistic factors include similar appearance (similarity principle), potential contours (closure principle), continuation (continuity principle), proximity (proximity principle), and direction (common fate principle) et al. Most of these factors are applied to static graphics. However, the direction becomes a dynamic factor that is particularly relevant for motion. In the context of robotic movement, direction is a ubiquitous and fundamental element that remains consistent across variations in robot size, speed, and other variables. Hence, it serves as a universal overarching element for analyzing emotional expression effects. We categorized all motion directions into two main types: horizontal and vertical. In the realm of interaction, horizontal motion further subdivides into approaching and distancing from the target object, while vertical motion encompasses two distinct forms: upward for positive direction and downward for negative direction.

Then, we used SOR theory to find other holistic factors. The SOR theory suggests that stimuli trigger responses based on the internal sensations or behaviors of the organism (human), and this process involves the sequence of stimulus-individual (emotion) -trigger response [25]. Among these elements, stimulation is one of the transferable holistic factors, and response is presented through horizontal movement. By combining Gestalt theory, the expression framework employed in this study is structured as follows: stimuli (including two types of positive and negative stimuli) - vertical movement (including vertical upward, vertical downward, and repetitive movements in both directions) - response (horizontal movement approaching and moving away from the presentation decision). The relevant holistic factors include stimulation, vertical movement direction, horizontal movement direction, and vertical repetition. The theoretical framework guiding our analysis is outlined as Fig. 1.
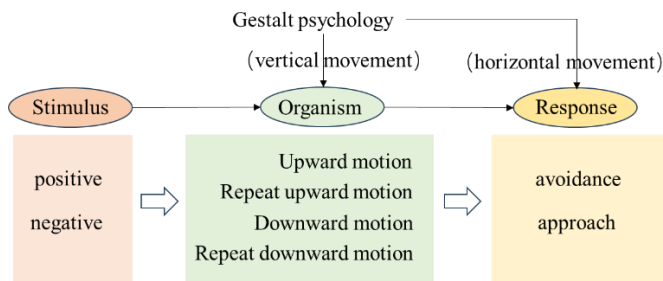
Fig. 1. Theoretical framework of the experiment.

Given the critical role of movement direction in our study, we began by analyzing the contributions of vertical and horizontal motions in the context of emotional expression to clarify their respective mechanisms for conveying emotions. According to the approach-withdrawal theory [26], we established a connection between horizontal movement and emotional valence, with approach signifying positive valence and avoidance and withdrawal signifying negative valence. The theory of embodied emotions [27] further underscores the influence of actions on the generation and perception of emotions. Consequently, positive actions can engender positive emotions, and conversely, negative actions can induce negative emotions. By extension, vertical movement aligns with the tenets of the embodied emotion theory, wherein upward motion signifies positive valence and downward motion signifies negative valence.

Notably, the valence dimension is the most basic and important aspect of the classical dimensional emotion model: Pleasure-Arousal-Dominance (PAD) model [25], which describes the range of changes in emotions from pleasant to unpleasant [28]. Compared to arousal (which represents the degree of emotional activation and is used to indicate the intensity of response to external stimuli) and dominance (which focus on the individual's control or influence over the external environment or other people, reflecting the individual's state of interaction with the environment or others), pleasant is more generalized and representative in presenting the overall emotional content. Since pleasure mainly depends on the robot's current motivation and goals [29], and it significantly informs the expresser's strategic choices in subsequent social interactions [30], the display of valence has a decisive impact on the overall emotional recognition results. Many studies on emotional expression also mainly focus on the expression of pleasure [31] [9]. In light of these considerations, we pose the question: in scenarios where both vertical and horizontal directions are concurrently present, which direction will more affect valence recognition, and how do these combined movements collectively convey emotional content?

Therefore, we have taken the following three hypotheses based on the above discussions:

$H_1$: Vertical movement has the same function as horizontal movement, which can demonstrate emotional valence.

$H_2$: When vertical and horizontal movements co-occur, one side predominates in expressing emotional valence.

$H_3$: Employing holistic factors enables non-humanoid robots to convey understandable emotional content to humans.

In this study, we first analyzed the expressive value of a single direction of motion. Subsequently, we explored the value of various holistic expression factors within the theoretical framework. These factors encompass vertical motion direction, horizontal motion direction, stimulation, and vertical repetitive motion as holistic expression factors.

## III. FACTOR ANALYSIS OF VALENCE EXPRESSION

In this study, we firstly investigated $H_1$, which posits that non-humanoid robots can convey emotional valence through vertical up-and-down movements. Additionally, we examined potential variations in recognition outcomes resulting from different types of motion modes used to achieve vertical movement.

### A. Methods

*1) Materials:* The movements that can achieve up-and-down movement in the vertical direction are translational movement and rotation. Therefore, we needed to confirm that rotating and moving on the vertical direction show the same effect. Based on the different modes of movement, we chose to use two non-humanoid robots—a spider robot and a mechanical arm—as the research objects. The spider robot allowed the body to move up and down through the support of four legs, and the robotic arm achieved the result of up and down movement by rotating.

We used the open-source animation software Blender to create simulation animations. In a total of four films, the two robots alternately went up and down to the limits of their own ranges of motion. The mechanical arm moved up and down by rotating, and the body of the spider robot moved up and down by translational motion. See Fig. 2. Then, participants evaluated the level of pleasure based on the animation contents. Data analysis used IBM SPSS Statistics 25. Materials are available at https://doi.org/10.6084/m9.figshare.23695926.v1

*2) Participants:* Participants were recruited through advertisements. 31 people (14 males, 17 females) with an age range of 18–43 (M = 28, SD = 6.5), 13 of whom had arts and humanities backgrounds, 8 had business and management backgrounds, and 9 had backgrounds in natural science and technology. Participants received a gift after the experiment. The protocol was approved by the Ethics Committee of the author's institution.

*3) Task and procedure:* Before the experiment, each participant was asked to sign a consent form and fill out demographic information. Participants were informed of task content. After the participants were ready, the simulation animation started, each animation played 3 times. After each animation finished, participants then chose the level of pleasure they felt from the robot's performance. In order to obtain more intuitive and efficient recognition results, we used the Self-Assessment Manikins (SAM) questionnaire [32] to acquire insights into how participants perceive the robot emotion [33]. Options were scored on a five-point Likert scale, with 1 being very unpleasant and 5 being very pleasant.

After the rating was completed, we started playing the next video. There were four videos in total. The experiment took an average of 7 minutes for each person.
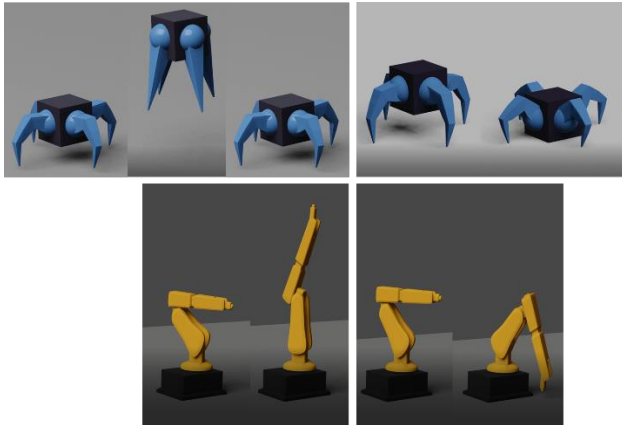


Fig. 2. Vertical movement of the robots for emotional expression. Top left: Spider robot moves upward; Top right: Spider robot moves downward; Bottom left: Mechanical arm upward movement; Bottom right: Mechanical arm downward movement.

### B. Results

To analyze the valence of the robot in the case, we plotted a mean bar chart. We used an independent sample T-test to examine the differences between different emotional groups.

Fig. 3 illustrates that there was no statistically significant difference in the recognition results for upward movement between the spider robot and the mechanical arm (t (60) = 0.381, p = 0.705). Likewise, no statistically significant difference was found in the results of downward movement between the two robots (t (60) = 0.131, p = 0.896). However, significant differences were observed in the motion recognition results of the same robot for positive and negative valence (p < 0.001).

To establish the range of valence recognition values within the sample's population, we performed a Z-test (z = 2.58) to calculate the 99% confidence interval for each parameter's estimated values, as presented in Table I.

Analysis of the data reveals that both the Spider robot and the Mechanical Arm consistently achieve valence recognition scores above 3.36 with a 99% confidence level for upward motion, while the probability of their downward motion scores falling below 2.59 was also above 99%. Emotions with scores above 3 on the 5-point scale were deemed positive, while those below 3 were considered negative. Thus, the statistical results confirmed a 99% probability of upward movement conveying positive emotions and downward movement conveying negative emotions. These findings support $H_1$, demonstrating that vertical movement serves the same purpose as horizontal movement in conveying emotional valence. Additionally, it is observed that achieving the same directional motion through various motion modes produces consistent results.

### C. Discussion

Through simulation experiments on two non-humanoid robots that achieve vertical motion through rotation and movement, we confirmed that the motion mode has no significant impact on emotion recognition results. Which means that the expression of motion in the same direction for non-human robots with different modes of motion results in the same outcome. Therefore, we can choose one of the robots as the research representative in the following direction-related research, and the results obtained can be generalized to a certain extent.
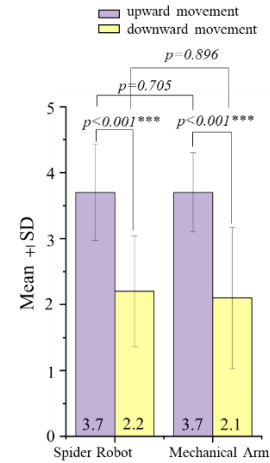


Fig. 3. Pairwise comparison between valence levels of robot emotions parameters.

TABLE I. 99% CONFIDENCE INTERVAL OF THE POPULATION TO WHICH EACH GROUP OF SAMPLES BELONGS TO THE RECOGNITION RESULTS

| 99% confidence interval | | |
|---|---|---|
| *movement* | *Spider robot* | *Mechanical Arm* |
| Upward movement | [3.36, 4.04] | [3.41, 3.98] |
| Downward movement | [1.81, 2.59] | [1.61, 2.59] |

At the same time, the experiment confirms $H_1$, which suggests that vertical and horizontal movements serve the same function in demonstrating emotional valence. Accordingly, we have demonstrated the value of embodied theory in emotional action recognition, where positive behavioral actions can lead to positive emotional recognition results, and vice versa. This conclusion lays the groundwork for $H_2$ and $H_3$.

## IV. EFFECT OF HOLISTIC EXPRESSION FACTORS

It was previously verified that both vertical and horizontal movements have the function of displaying valence. Therefore, we further verified the latter two assumptions, namely $H_2$: When both vertical and horizontal movements occur, one of them dominates the display of emotional valence. $H_3$: Employing holistic factors enables non-humanoid robots to convey understandable emotional content to humans.

In order to focus on the research content, we first discussed the methods of motion combination, and then conducted experiments based on the theoretical framework and analyzed the relationship between the factors and the results.

### A. Analysis of Motion Combination Methods

Emotions often appear in complex [34] and varied forms [35]. Due to the fluid and intricate nature of emotions, not all

emotional expressions exhibit distinct stages in real-life scenarios. It is also possible for concurrent of behavioral states in the 'trigger phase' and 'response phase'. Therefore, when horizontal and vertical motions occur simultaneously, there is more than one relationship between the two motions. Define the horizontal motion as $H_M$, the vertical motion as $V_M$, $t$ as the time, $n$ is the minimum interval time step between the two movements. The expressions for the two movements are as follows:

Define Action Expression as

$$\vec{A}_E\left(t,n\right)=\left(\vec{V}_M^t+\vec{H}_M^{t+n}\right) \tag{1}$$

When the two are in a sequential relationship,

$$n=1,$$
$$\vec{A}_E\left(t,1\right)=\left(\vec{V}_M^t+\vec{H}_M^{t+1}\right) \tag{2}$$

To simplify the description, the sequential relationship described in formula (2) in the following text is denoted as $V_M\oplus H_M$.

When the two are in a parallel relationship,

$$n=0,$$
$$\vec{A}_E\left(t,0\right)=\left(\vec{V}_M^t+\vec{H}_M^t\right) \tag{3}$$

To simplify the description, the parallel relationship described in formula (3) below is denoted as $V_M\otimes H_M$.

The two formulas describe two different relationships, with the difference being that $V_M\oplus H_M$ describes a horizontal movement that occurs after a vertical movement, and $V_M\otimes H_M$ means during the process of horizontal movement, multiple vertical movements occur simultaneously.

Since $V_M$ = {Upward movement, Downward movement}, $H_M$ = {Approach, Avoidance}, there are various types of motion combinations. The emotional valence recognition results obtained from actions with the same semantics will not change, which means when $V_M$ = Upward movement, $H_M$ = Approach, both vertical and horizontal directions exhibit positive semantics, ultimately resulting in a positive valence. Similarly, when $V_M$ = Downward movement, $H_M$ = Avoidance, the combination of two negative semantic movements results in a negative valence.

One of our research goal was to understand the role of different movement directions in emotional expression. Therefore, we mainly focused on the results obtained by combining a positive and a negative action. In addition, in order to simulate real-life scenario responses, we classified environmental stimuli into two types: positive and negative stimuli. Therefore, there were a total of eight experimental situations. See Table II.

## B. Methods

*1) Materials:* In the first study, we confirmed that the recognition effect of both translational movement and rotation in the vertical direction was identical. Therefore, we only used one of the robots in this experiment. We chose the spider robot for analysis since it was equipped to move both vertically and horizontally at the same time. Similarly, we also used the open-source software Blender to model animations. Participants filled out questionnaires after watching the animations. In order to minimize the influence of environmental colors on the recognition results, we set all backgrounds to a neutral gray shade.

TABLE II.    SUMMARY OF EXPERIMENTAL GROUP

| Stimulation | Motion relationship | Contents | Abbreviation |
|---|---|---|---|
| Positive | $V_M\oplus H_M$ | Upward movement $\oplus$ Avoidance | $P:U_M\oplus A_v$ |
| | | Downward movement $\oplus$ Approach | $P:D_M\oplus A_p$ |
| | $V_M\otimes H_M$ | Upward movement $\otimes$ Avoidance | $P:U_M\otimes A_v$ |
| | | Downward movement $\otimes$ Approach | $P:D_M\otimes A_p$ |
| Negative | $V_M\oplus H_M$ | Upward movement $\oplus$ Avoidance | $N:U_M\oplus A_v$ |
| | | Downward movement $\oplus$ Approach | $N:D_M\oplus A_p$ |
| | $V_M\otimes H_M$ | Upward movement $\otimes$ Avoidance | $N:U_M\otimes A_v$ |
| | | Downward movement $\otimes$ Approach | $N:D_M\otimes A_p$ |

The focus of this study was solely on exploring the impact of motion direction. To minimize interference, all videos maintained consistent speed, motion distance, and fixed motion amplitude (the highest reaching position of the spider robot body was 50.7cm, the middle height position was 30.6cm, and the lowest height position was 15.0cm). The distinction arises from the fact that movements that occur in parallel will experience multiple vertical up and down movements, resulting in variations in the total duration. A total of 8 videos were included, see Fig. 4. To mitigate mutual influence between similar movement expressions, the videos were played back in the following order: 1) $N:U_M\oplus A_v$ , 2) $N:D_M\oplus A_p$ , 3) $N:U_M\otimes A_v$ , 4) $N:D_M\otimes A_p$ . Then, display videos in the same order under positive stimuli. Materials are available at https://doi.org/10.6084/m9.figshare.23695926.v1

*2) Participants:* Participants were recruited through advertisements. 35 people (20 males, 15 females) from school. The age range was 18-42 (M = 27, SD = 5.9), 11 were from arts and humanities background, 6 were from business background, and 18 were from science and technology background. Participants received a gift after the experiment. The protocol was approved by the Ethics Committee of the author's institution.

*3) Procedure:* Before the experiment, each participant was asked to sign a consent form and fill out demographic information. Participants were informed of task content. After the participants were ready, the experiment began.

Firstly, an introduction of the video was showed: "The following is the emotional expression of the robot after being praised (positive stimulus) /criticized (negative stimulus) by the owner. Please choose according to the requirements." Secondly, the animations were played. The animation began with the host's expression, with a smile representing positive stimulation and an angry expression representing negative stimulation. Subsequently, the robot actions were presented. See Fig. 4. Each animation played 3 times.
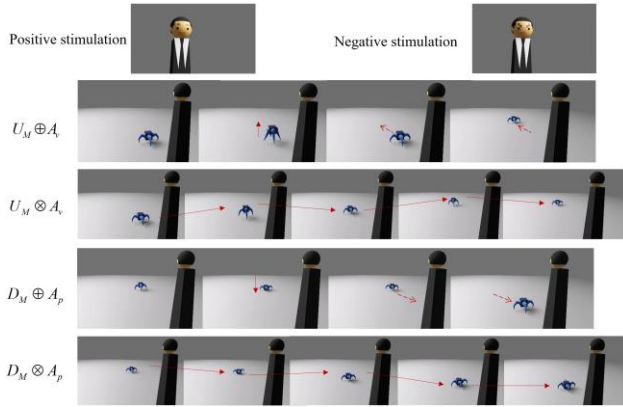


Fig. 4.    Screenshots of the animations used in the experiment.

After viewing each video, participants were required to choose the pleasure level of the robot's performance as their initial response. We also used the SAM questionnaire [32]. The options were rated on a five-point Likert scale, ranging from one (very unpleasant) to five (very pleasant). Secondly, the content of different PAD emotional spaces was described using Gebhard's classification method [36], which associates various types of emotions with each emotional space. Subsequently, participants selected the emotional types of robot actions observed in the video based on their own cognition. The specific emotional options correspond to the emotional space as shown in Table III. Participants were only able to view the available options and their corresponding emotional types without direct visibility of the associated PAD emotional space. After the questionnaire ended, we continued to play the next video. The experiment took an average of 20 minutes for each person.

*C. Results*

*1) Pleasure:* To comprehend the roles played by different factors in the expression process, we employed Multi-way ANOVA to examine participants' recognition of the pleasure conveyed by non-humanoid robots. Independent variables included stimuli, motion groups (Group 1: Upward movement and Avoidance, Group 2: Downward movement and Approach), and vertical repetition, while the dependent variable was recognition pleasure. Table IV displays participants' chosen pleasure levels for each group.

The results indicate that, firstly, different stimuli had a significant impact on pleasure recognition, and the main effect of the stimuli was statistically significant (F = 40.381，df = 1，P < .001，$\eta^2$ = .129). Secondly, different combinations of motion have no significant difference in recognition results (F=

.248，df =1，P = .619). Thirdly, vertical repetition significantly influenced valence recognition, and the main effect of repetition was statistically significant (F = 10.495，df = 1，P = .001，$\eta^2$ = .037). Finally, there was a significant interaction effect between the motion group and vertical repetition (F = 5.030，df = 1，P = .026，$\eta^2$ = .018). These findings were reaffirmed through independent sample T-tests for inter-group comparisons, as shown in the bar chart in Fig. 5.

TABLE III.    EMOTIONAL OPTIONS AND EMOTIONAL SPACE CORRESPONDENCE TABLE

| Emotional choices | PAD space | Emotional choices | PAD space |
|---|---|---|---|
| A gratitude, liking | +P+A-D | B docile | +P-A-D |
| C pride, HappyFor | +P+A+D | D relief, relaxed | +P-A+D |
| E anger，hate | -P+A+D | F disdainful, reproach | -P-A+D |
| G shame, fear | -P+A-D | H pity, bored | -P-A-D |
| I Others （fill in the content） | | | |

TABLE IV.    STATISTICS OF THE NUMBER OF PEOPLE SELECTED FOR EACH GROUP'S PLEASURE LEVEL

| | Very un-pleasure | Un-pleasure | Neutral | Pleasure | Very pleasure |
|---|---|---|---|---|---|
| $P:U_M \oplus A_v$ | 1 (2.9%) | 5 (14.3%) | 13 (37.1%) | 14 (40%) | 2 (5.7%) |
| $P:U_M \otimes A_v$ | 2 (6%) | 3 (9%) | 4 (11%) | 11 (31%) | 15 (43%) |
| $N:U_M \oplus A_v$ | 3 (9%) | 17 (48%) | 10 (29%) | 4 (11%) | 1 (3%) |
| $N:U_M \otimes A_v$ | 3 (9%) | 11(31.5%) | 5 (14%) | 11 (31.5%) | 5 (14%) |
| $P:D_M \oplus A_p$ | 0 (0%) | 5 (14.2%) | 13 (37.1%) | 13 (37.1%) | 4 (11.6%) |
| $P:D_M \otimes A_p$ | 1 (2.9%) | 3 (8.5%) | 8 (22.9%) | 23 (65.7%) | 0 (0%) |
| $N:D_M \oplus A_p$ | 1 (2.9%) | 11 (31.5%) | 18 (51.4%) | 5 (14.2%) | 0 (0%) |
| $N:D_M \otimes A_p$ | 2 (6%) | 8 (23%) | 15 (43%) | 10 (28%) | 0 (0%) |

These results address H$_2$, which showed that the presence of both vertical and horizontal movements does not result in a dominant emotional valence expression. Recognition results are collectively influenced by stimuli, vertical repetition, and the interaction between various movement directions and vertical repetition. Thus, H$_2$ is unsupported.

To further assess the interactive effects of the exercise group and vertical repetition, we conducted a simple effect analysis. The analysis revealed a significant simple effect of vertical repetition in the upward movement and avoidance group (F = 15.03, df = 1, P < .001), but not in the downward movement and approach group (F = 0.497, df = 1, P = .482). Subsequently, we conducted independent sample t-tests between groups once more, resulting in consistent results. See Fig. 6.

In the upward movement and avoidance group, both under positive stimulation (t (68) = -2.59, P = 0.012) and negative stimulation (t (68) = -2.28, P = 0.026), vertical repetition significantly influenced the results. There was no significant difference in the results between vertical repetitions group and

the downward movement and approach group under positive stimulation (t (68) = -0.286, P = 0.776) and negative stimulation (t (68) = -0.891, P = 0.376).



Fig. 5.   Pairwise comparison of the average value of pleasure recognition under positive and negative stimuli in four groups.
* p < 0.05, ** p < 0.01, *** p < 0.001

*2) Analysis of specific emotional contents:* To address $H_3$, we analyzed the specific emotional types chosen by participants for each video. The specific content

corresponding to each option is shown in Table II, and the results of the selected number of people are shown in Table V.
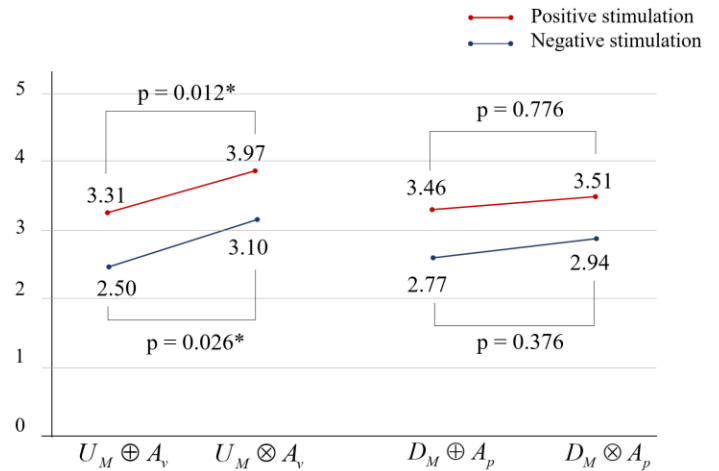


Fig. 6.   Comparison of mean values between single and repeated movements in the vertical direction.

The chi-squared goodness-of-fit test results indicated that the participants' choice differed significantly from a uniform distribution. The answers with the highest number of votes were generally statistically significant. The specific results of emotion recognition are shown in Table VI.

According to the findings, non-humanoid robots' emotions can be expressed by using holistic expression factors, and answers can be acquired that are both concise and relatively unified. Thus, $H_3$ is supported.

TABLE V.          NUMBER OF PEOPLE SELECTED FOR EACH EMOTIONAL CHOICE

| | $P:U_M \oplus A_v$ | $P:U_M \otimes A_v$ | $N:U_M \oplus A_v$ | $N:U_M \otimes A_v$ | $P:D_M \oplus A_p$ | $P:D_M \otimes A_p$ | $N:D_M \oplus A_p$ | $N:D_M \otimes A_p$ |
|---|---|---|---|---|---|---|---|---|
| A (+P+A-D) | 5 | 6 | 1 | 1 | 8 | 3 | 1 | 2 |
| B (+P-A-D) | 1 | 2 | 4 | 1 | 8 | 11 | 19 | 11 |
| C (+P+A+D) | 4 | 13 | 1 | 4 | 4 | 2 | 0 | 3 |
| D (+P-A+D) | 12 | 9 | 2 | 11 | 10 | 13 | 3 | 1 |
| E (-P+A+D) | 4 | 5 | 5 | 9 | 0 | 0 | 0 | 1 |
| F (-P-A+D) | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 13 |
| G (-P+A-D) | 7 | 0 | 20 | 7 | 4 | 5 | 11 | 0 |
| H (-P-A-D) | 2 | 0 | 1 | 1 | 0 | 1 | 0 | 1 |
| I Others | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 no sure |
| Sig. | $X^2 = 5$, p = .014 | $X^2 = 4$, p = .040 | $X^2 = 4$, p = .000 | $X^2 = 4$, p = .246 | $X^2 = 3$, p = .004 | $X^2 = 5$, p = .001 | $X^2 = 3$, p = .000 | $X^2 = 4$, p = .004 |

TABLE VI.        SIGNIFICANT EMOTIONAL OPTIONS IN EACH GROUP'S RECOGNITION RESULTS

| Group | PAD result | Emotion content |
|---|---|---|
| $P:U_M \oplus A_v$ | D (+P-A+D) | relief, relaxed |
| $P:U_M \otimes A_v$ | C (+P+A+D) | pride, Happy For |
| $N:U_M \oplus A_v$ | G (-P+A-D) | shame, fear |
| $N:U_M \otimes A_v$ | -- | -- |
| $P:D_M \oplus A_p$ | D (+P-A+D) | relief, relaxed |
| $P:D_M \otimes A_p$ | D (+P-A+D) | relief, relaxed |
| $N:D_M \oplus A_p$ | B (+P-A-D) | docile |
| $N:D_M \otimes A_p$ | F (-P-A+D) | Disdainful, reproach |

## D. Discussion

This experiment firstly invalidated $H_2$, indicating no dominant direction between vertical and horizontal movements in emotional valence recognition. In order to understand the value of factors in emotional expression, the study further analyzed the effects of environmental stimuli, movement direction, and repetition on emotional expression. Analysis results revealed significant differences in valence recognition due to positive and negative stimuli, vertical repetition, and the interaction between vertical repetition and movement direction. This is because: 1) The vertical and horizontal movement directions have similar effects in expressing valence. Forward and jumping express positive valence, while backward and downward movement express negative valence. 2) When the two directions are mutually exclusive in valence expression, the environmental stimuli has a guiding effect on the recognition results. Under the prompts and guidance of different types of stimuli, participants tend to focus on different types of actions and choose different valence results. Therefore, under positive stimuli, the results tend to be biased towards positive valence. Under negative stimuli, the results tend to be biased towards negative valence.

Additionally, the interaction effect between vertical repetition and motion direction groups significantly influenced recognition results. However, no significant recognition was observed in the downward movement and approach groups ($D_M \oplus A_p$ and $D_M \otimes A_p$). Upon analysis, firstly, we found that under positive stimuli, the approach motion was associated with positive emotions and was more likely to capture attention. Conversely, downward movements, including repeated downward motions, were likely to be ignored as conveying negative expressions. Thus, influenced by positive stimulus scenarios, observers' subconscious neglect for vertical repeating motion caused no significant difference in recognition results. Secondly, under negative stimuli, the emotion type with significant recognition results in $N:D_M \oplus A_p$ was B (+P-A-D): docile; the types of emotions with significant recognition results in group $N:D_M \otimes A_p$ was F (-P-A+D): disdainful/reproach. As the participants were only presented with options of emotional types without specific

valence dimensions during the decision-making process, they tended to observe all options and select a consistent emotional attitude. Therefore, by comparing the results of B (+P-A-D): docile and F (-P-A+D): disdainful/reproach, it can be found that repetitive downward movement resulted in a certain degree of decrease in pleasure, but the difference had not yet reached a significant level. Moreover, repetition downward changed the robot from displaying obedience to expressing blame, and its dominance (D) increased from weak to strong. Previous studies have found that the straightness of the spine is seen as a display of prestige [37]. Vertical movement, to some extent, signifies the straightness of the spine. A single downward movement implies spinal curvature, reminiscent of obedience and displaying a submissive stance. Conversely, multiple downward movements necessitate a continuous cycle of returning upward to the initial position and repeating the downward movement. This leads to a visual repetition of upward and downward movement in the vertical direction, emphasizing the vertical trajectory to some extent. This emphasis on the path suggests the straightness of the spine and enhances the expression of emotional dominance.

Secondly, the research results on emotional content selection verified $H_3$: by utilizing holistic factors, non-humanoid robots can effectively convey comprehensible emotional categories to humans. Only $N:U_M \otimes A_v$ cannot be recognized as a relatively unified emotional type. From the previous research results, it can be seen that both stimulation and vertical repetition have a significant impact on the recognition of pleasure. Therefore, under negative stimuli, the positive valence conveyed by vertical repetition conflicts with the negative valence emphasized by negative stimuli, making it challenging for participants to determine a unified and precise emotional result. This happens because our study was designed to discuss the effects of different factors. Emotional expression in real emotional expression environments should be more unified on the expression, and future robot emotional expression should minimize conflicting expressions to enhance user recognition.

Thirdly, detailed research outcomes are outlined in Table VII. After conducting a comprehensive analysis, the following conclusions can be drawn:

TABLE VII. RECOGNITION RESULTS

| stimuli | Vertical movement | Horizontal movement | Valence | Effect of vertical repeated on valence | Emotional results | Examples |
|---|---|---|---|---|---|---|
| +[a] | + | − | + | significant increase | +P-A+D | $P:U_M \oplus A_v$ |
| + | Multiple + | − | + | | +P+A+D | $P:U_M \otimes A_v$ |
| + | − | + | + | no significant change | +P-A+D | $P:D_M \oplus A_p$ |
| + | Multiple − | + | + | | +P-A+D | $P:D_M \otimes A_p$ |
| − | + | − | − | significant increase | -P+A-D | $N:U_M \oplus A_v$ |
| − | Multiple + | − | − | | / | $N:U_M \otimes A_v$ |
| − | − | + | − | no significant change | +P-A-D | $N:D_M \oplus A_p$ |
| − | Multiple − | + | − | | -P-A+D | $N:D_M \otimes A_p$ |

- The recognition of robot valence and emotions by users is collectively influenced by various factors, including stimuli, vertical repetition, and motion direction.

- Confusion and identification difficulties can arise when expressive factors contradict the intended emotional expression. Future design should aim to avoid situations where factors are mutually exclusive.

- Under the influence of stimuli, the combination of vertical and horizontal movements helps to intuitively display complex emotions by demonstrating valence and a certain degree of emotional dominance. However, further research is needed on the factors that affect the expression of dominance.

## V. GENERAL DISCUSSION

Through subjective measurement methods, we found the potential rules that worked in humans recognizing emotional actions. Through experiments, we confirmed the role of holistic factors in the hypothesis. Meanwhile, this study validated the effect of Gestalt theory on emotion recognition.

The value of holistic expression factors lies in finding decisive expression elements from complex factors, which to some extent reduces the difficulty of expression for non-humanoid robots and achieves simplification of complex problems. For robots with a high degree of anthropomorphism, there are many factors that can help express emotions, but the effects of these factors are random. When faced with different types of robot expression tasks, designers often find it difficult to judge and select truly valuable expression elements, and the quality of expression results is also difficult to predict. Therefore, the analysis of universal holistic factors helps us understand the key elements that truly play a role in expression, allowing designers to more efficiently select and apply relevant expression materials for design. At the same time, these holistic elements are also important feature vectors for various types of robots in the future to achieve autonomous expression using algorithms. As a result, this study provides new ideas for the future development of emotion expression in non-humanoid robots.

## VI. CONCLUSION

The growing integration of non-humanoid robots into social life has elevated the significance of researching their capabilities of emotional expression. In this study, we introduced holistic expression factors and theoretical frameworks based on Gestalt theory and SOR theory. Subsequently, we performed experiments to validate the function of these holistic expression factors and their influence on emotional expression.

In the first experiment, we confirmed the significance of horizontal and vertical movement directions in conveying emotional valence. In the second experiment, we examined the influence of stimuli, movement direction, repetition, and their collective impact on emotional expression as holistic expression factors. When a non-humanoid robot can move both vertically and horizontally, there is no dominant direction influencing valence recognition results. Recognition results are affected by environmental stimuli, vertical repetitive movements, and the interplay of factors. The results indicate that horizontal and vertical motion expressions can influence the manifestation of valence and emotional dominance based on environmental stimuli, thereby helping non-humanoid robots to present emotionally recognizable content to humans.

These results validate that human perception of emotional expression actions is also influenced by a holistic perspective, introducing a novel viewpoint into the process of designing emotional motions for robots. In consequence, it shifts the conventional understanding among robot emotion expression designers, emphasizing that robots can convey emotions beyond mere imitation of specific human or organismic characteristics. Adopting a holistic approach enables various types of non-humanoid robots to improve the efficiency of their expression.

Future research can investigate the holistic expression factors related to emotional arousal and emotional dominance, enabling non-humanoid robots to convey a wider range of emotions.

## REFERENCES

[1] Bonarini, "Can my robotic home cleaner be happy? Issues about emotional expression in non-bio-inspired robots," Adaptive Behavior, 2016.

[2] T. Law, J. D. Leeuw, J. H. Long, "How Movements of a Non-Humanoid Robot Affect Emotional Perceptions and Trust," International Journal of Social Robotics, 2020.

[3] M. Faria, A. Costigliola, P. Alves-oliveira, et al., "Follow me: Communicating intentions with a spherical robot," proceedings of the 25th IEEE International Symposium on Robot and Human Interactive Communication (RO-MAN), 2016 .

[4] G. I. Na, L. PA, P. Keepon, et al., "A playful robot for research, therapy, and entertainment," Intjsocial Robotics, 2009.

[5] M. Szabóová, M. Sarnovsky, V. Kreňáková, et al., "Emotion Analysis in Human–Robot Interaction," Electronics, 9(11): 1761, 2020.

[6] J. R. Cauchard, K. Y. Zhai, M. Spadafora, et al., "Emotion Encoding in Human-Drone Interaction," The Eleventh ACM/IEEE International Conference on Human Robot Interaction. Christchurch, New Zealand; IEEE Press, pp. 263–270, 2016.

[7] G.Venture, D. Kuli, "Robot Expressive Motions: A Survey of Generation and Evaluation Methods," proceedings of the ACMPUB27New York, NY, USA, 2019.

[8] T. R. Groechel, Z. Shi, R. Pakkar, et al., "Using Socially Expressive Mixed Reality Arms for Enhancing Low-Expressivity Robots ," IEEE, 2019.

[9] A. Valenti, A. Block, M. Chita-tegmark, et al., "Emotion Expression in a Socially Assistive Robot for Persons with Parkinson's Disease," 2020.

[10] D. O. Johnson, R. H. Cuijpers, "Investigating the Effect of a Humanoid Robot's Head Position on Imitating Human Emotions," International Journal of Social Robotics, 2017.

[11] R. Savery, R. Rose, G. Weinberg, "Establishing Human-Robot Trust through Music-Driven Robotic Emotion Prosody and Gesture," IEEE, 2020.

[12] T. Ribeiro, A. Paiva. "Nutty-based Robot Animation -- Principles and Practices," 2019

[13] D. Szafir, B. Mutlu, T. Fong, "Communication of Intent in Assistive Free Flyers," proceedings of the Acm/ieee International Conference on Human-robot Interaction, 2014.

[14] J. Forlizzi, C. Bartneck, J. Yamato, et al., Bringing Robots To Life: Applying Principles Of Animation To Robots. 2004.

[15] R, Laban, L. Ullmann, "The Mastery of Movement," Creative Activities, pp: 200, 1971.

[16] S. J. Burton, A. A. Samadani, R. Gorbet, et al., "Laban Movement Analysis and Affective Movement Generation for Robots and Other Near-Living Creatures," Springer International Publishing, 2016.

[17] R. Urtasun, P. Glardon, R. Boulic, et al., "Style-ased Motion Synthesis," Computer Graphics Forum, 23(4): 799-812, 2004.

[18] O. Alemi, W. Li, P. Pasquier, "Affect-expressive movement generation with factored conditional Restricted Boltzmann Machines," proceedings of the International Conference on Affective Computing & Intelligent Interaction, 2015 .

[19] Z. Wang, K. Muelling, M. P. Deisenroth, et al., "Probabilistic movement modeling for intention inference in human–robot interaction," International Journal of Robotics Research, 2013.

[20] H. J. Smith, C. Cao, M. Neff, et al., "Efficient Neural Networks for Real-time Motion Style Transfer," Proc ACM Comput Graph Interact Tech, 2(2): Article 13, 2019.

[21] S. Hou, W. Xu, J. Chai, et al., "A Causal Convolutional Neural Network for Motion Modeling and Synthesis," 2021.

[22] G. Nie, Y. Zhan, "A Review of Affective Generation Models," arXiv: 2202.10763, 2022.

[23] H. Du, E. Herrmann, J. Sprenger, et al., "Stylistic Locomotion Modeling and Synthesis using Variational Generative Models," Motion, Interaction and Games, 2019.

[24] W. Kohler, "Gestalt Psychology," The New American Library, 1947.

[25] A. Mehrabian, J. A. Russell, An approach to environmental psychology. Cambridge: MIT Press, 1974.

[26] A. J. Elliot, A. B. Eder, Harmon-Jones E. "Approach-Avoidance Motivation and Emotion: Convergence and Divergence," Emotion Review, 5(3): 308-11, 2013.

[27] J. D. Laird, K. Lacasse, "Bodily Influences on Emotional Feelings: Accumulating Evidence and Extensions of William James's Theory of Emotion," Emotion Review, 6(1): 27-34, 2014.

[28] J. A. Russell, "A Circumplex Model of Affect," Journal of Personality and Social Psychology, 39(6): 1161-78, 1980.

[29] S. H. Paplu, C. Mishra, K. Berns, "Real-time Emotion Appraisal with Circumplex Model for Human-Robot Interaction," arXiv, 2022.

[30] N. Spatola, O. A. Wudarczyk, "Implicit Attitudes Towards Robots Predict Explicit Attitudes, Semantic Distance Between Robots and Humans, Anthropomorphism, and Prosocial Behavior: From Attitudes to Human–Robot Interaction," International Journal of Social Robotics, pp: 1-11, 2020.

[31] I. Leite, C. Martinho, A. Pereira, et al., "iCat: an Affective Game Buddy Based on Anticipatory Mechanisms," proceedings of the 7th International Joint Conference on Autonomous Agents and Multiagent Systems (AAMAS 2008), Estoril, Portugal, May 12-16, Volume 3, 2008 .

[32] M. M. Bradley, P. J. Lang, "Measuring emotion: the Self-Assessment Manikin and the Semantic Differential," Journal of behavior therapy and experimental psychiatry, 25(1): 49-59, 1994.

[33] J. Xu, J. Broekens, K. Hindriks, et al., "Mood contagion of robot body language in human robot interaction," Autonomous Agents & Multi-Agent Systems, 2015.

[34] J. Elster, "Strong feelings: emotion, addiction, and human behavior," Jean Nicod Lectures, 2000.

[35] R. Plutchik, The nature of emotions: Human emotions have deep evolutionary roots, 2001.

[36] P. Gebhard, "ALMA: a layered model of affect," proceedings of the 4th International Joint Conference on Autonomous Agents and Multiagent Systems (AAMAS 2005), July 25-29, Utrecht, The Netherlands, 2005.

[37] R. Krner, A. Schütz, "Dominance or prestige: A review of the effects of power poses and other body postures," Social and Personality Psychology Compass, 2020.

# Deep CNN for the Identification of Pneumonia Respiratory Disease in Chest X-Ray Imagery

Dias Nessipkhanov[1], Venera Davletova[2], Nurgul Kurmanbekkyzy[3], Batyrkhan Omarov[4]

International Information Technology University, Almaty, Kazakhstan[1, 4]
Khoja Akhmet Yassawi International Kazakh-Turkish University, Turkistan, Kazakhstan[2]
Kazakh-Russian Medical University, Almaty, Kazakhstan[3]
Al-Farabi Kazakh National University, Almaty, Kazakhstan[4]
NARXOZ University, Almaty, Kazakhstan[4]

*Abstract*—**Addressing the challenges of diagnosing lower respiratory tract infections, this study unveils the potential of Deep Convolutional Neural Networks (Deep CNN) as transformative tools in medical image interpretation. Our research presents a tailored Deep CNN model, optimized for distinguishing pneumonia in chest X-ray images, a task often complicated by subtle radiological differences. We utilized an extensive dataset comprising 12,000 chest X-rays, which incorporated both pneumonia-affected and healthy samples. Through rigorous pre-processing, encompassing noise abatement, normalization, and data augmentation, a fortified training set emerged. This set was the basis for our Deep CNN, marked by intricate convolutional designs, planned dropouts, and modern activation functions. With 85% of images used for training and the balance for validation, the model manifested an impressive 98.1% accuracy, surpassing preceding approaches. Crucially, specificity and sensitivity metrics stood at 97.5% and 98.8%, highlighting the model's precision in segregating pneumonia cases from clear ones, thus reducing diagnostic errors. These results emphasize Deep CNN's transformative capability in pneumonia diagnosis via X-rays and suggest potential applications across various medical imaging facets. However, as we champion these outcomes, we must cognizantly assess potential hurdles in clinical application, encompassing ethical deliberations, model scalability, and its adaptability to ever-changing pulmonary disease profiles.**

*Keywords—X-Ray; deep learning; classification; respiratory disease; pneumonia; CNN*

## I. INTRODUCTION

The realm of medical imaging has witnessed an unprecedented surge in technological advancements over the past few decades. One of the most intriguing developments in this arena is the integration of artificial intelligence (AI) with radiological imaging techniques, a confluence that holds significant promise for the future of diagnostic medicine [1]. Deep learning, a subset of machine learning, which itself is a domain under the vast umbrella of AI, has shown transformative potential in various applications, and perhaps most profoundly in medical imaging [2]. At the heart of this deep learning revolution are the Convolutional Neural Networks (CNN), renowned for their capacity to process image data with precision, speed, and adaptability.

Pneumonia, a respiratory ailment primarily caused by bacteria, viruses, or fungi, remains one of the foremost global health challenges, claiming millions of lives annually [3]. Its early and accurate detection is paramount not only for the timely treatment of patients but also for mitigating its spread, particularly in institutional settings like hospitals. Traditional diagnostic methods, chiefly the analysis of chest X-ray images by radiologists, although effective, are not devoid of limitations. Human assessments can vary based on the experience of the radiologist, the quality of the X-ray image, and other external factors, sometimes leading to false negatives or positives [4]. Furthermore, in resource-constrained settings where the ratio of radiologists to patients is exceedingly low, a delay in diagnosis can exacerbate the ailment's morbidity.

Deep CNNs, with their multi-layered architecture, are particularly adept at extracting intricate features from images, making them an ideal choice for medical image analysis [5]. The multiple convolutional layers in these networks allow them to detect patterns at different levels of abstraction, from rudimentary edges to more complex structures, like tissues or organs [6]. When applied to chest X-ray images, this innate capability of CNNs can be harnessed to identify and differentiate between healthy lung tissues and those affected by pneumonia, thereby offering a granular, yet comprehensive analysis [7].

Given the critical role of chest X-ray images in the diagnosis of pneumonia, enhancing the precision of their analysis using Deep CNNs could be a game-changer [8]. While other imaging modalities like CT scans provide more detailed insights, they come with their set of challenges, including higher radiation doses and cost. Thus, optimizing the accuracy of X-ray image analysis, a relatively more accessible and cost-effective modality, can be instrumental in the global fight against pneumonia [9].

Several studies in the past have touched upon the integration of CNNs with medical imaging, but a focused exploration into the utilization of Deep CNNs for pneumonia detection in chest X-rays remains a niche yet incredibly vital research area. This study, therefore, seeks to bridge this gap by designing, implementing, and evaluating a bespoke Deep CNN model tailored for this purpose [10]. By employing a comprehensive dataset and adopting advanced training methodologies, this research aspires to push the boundaries of what's possible in pneumonia diagnosis using AI-driven methods [11]. Furthermore, it aims to shed light on the

potential challenges, ethical implications, and avenues for future research in this interdisciplinary domain.

In summary, the potential convergence of deep learning, especially Deep CNNs, with radiological techniques offers an exciting prospect for the realm of diagnostic medicine. This study endeavors to explore this synergy with a keen focus on the accurate classification of pneumonia from chest X-ray images. Through this research, we hope to contribute meaningfully to the ongoing dialogue about the future of AI in healthcare and its broader implications for patient care, medical training, and global health initiatives.

## II. RELATED WORKS

Deep learning methodologies, particularly Deep Convolutional Neural Networks (Deep CNNs), have carved a niche in the complex arena of medical image analysis. Their advent has ushered in a transformative phase in diagnostics, with a heightened emphasis on accuracy and speed [12]. A plethora of research endeavors have focused on integrating these networks for disease detection and classification from medical images, with pneumonia detection from chest X-rays being a focal point due to the ailment's global prevalence [13]. This section critically appraises seminal works that have laid the groundwork in this interdisciplinary domain and contextualizes their contributions in the larger tapestry of Deep CNN-driven pneumonia diagnosis.

### A. Traditional Techniques vs. CNNs

Before the dominance of Convolutional Neural Networks (CNNs) in medical imaging, the diagnostic realm heavily relied on traditional Computer-Aided Diagnosis (CAD) systems [14]. These systems were underpinned by rule-based algorithms, wherein features were manually engineered and extracted from images to assist in diagnoses. Such traditional methodologies primarily encompassed techniques like edge detection, histogram thresholding, texture analysis, and morphological operations [15]. These feature-extraction methods were pivotal for separating regions of interest from background noise in the images.

One of the studies to critically assess the transition from these traditional techniques to CNNs. Their study underlined the inherent limitations of CAD systems, especially their reliance on manually crafted features [16]. This manual dependence often led to inconsistencies, largely influenced by the experience of the technician, the quality of equipment, and the inherent variability of medical images. Moreover, these systems were often marred by a lack of adaptability, which meant that changing or updating the diagnostic criteria required significant overhauls.

Contrastingly, CNNs introduced a paradigm shift by autonomously extracting hierarchical features from images without explicit manual intervention [17]. This capability allows CNNs to adaptively discern and learn intricate patterns and anomalies in medical images, making them markedly superior in terms of adaptability and precision. Lakhani and Sundaram's comparison accentuated the reduction in false positives and negatives when employing CNNs, thus highlighting their potential in enhancing diagnostic accuracy [18].

Furthermore, traditional techniques, though effective in controlled environments, often faltered with data variability, such as differences in imaging devices, patient demographics, or image quality [19]. CNNs, on the other hand, showcased resilience against such variabilities, given their capacity to be trained on large and diverse datasets, enabling them to generalize better across different scenarios.

In conclusion, while traditional CAD systems laid the foundational groundwork for computer-assisted medical diagnostics, the introduction and subsequent evolution of CNNs have undeniably redefined the landscape. The transition from manual feature engineering to automated feature extraction not only bolstered accuracy but also introduced scalability and adaptability, crucial for the ever-evolving field of medical diagnostics. The insights provided by studies like that of Lakhani and Sundaram serve as a testament to the transformative impact of CNNs in the medical imaging domain.

### B. Basic CNN Architectures

Convolutional Neural Networks (CNNs), since their inception, have revolutionized image analysis due to their distinctive architectural elements tailored for hierarchical feature extraction [20]. At the foundational level, the basic CNN architecture is structured into three principal components: convolutional layers, pooling layers, and fully connected layers.

The convolutional layers, as the name suggests, apply convolution operations to the input image, extracting primary features like edges and textures [21]. These operations utilize small, learnable filters that slide over the input image, generating feature maps that capture spatial hierarchies and patterns. This localized feature detection contrasts starkly with traditional image processing techniques [22], enabling CNNs to capture intricate details with higher fidelity.

Pooling layers follow convolution operations and primarily function to reduce the spatial dimensions of the feature maps [23]. Commonly used pooling operations, such as max-pooling, retain the most prominent features while discarding redundant information. This dimensionality reduction not only enhances computational efficiency but also bolsters the model's translational invariance, ensuring that the CNN remains robust to slight shifts or rotations in the input [24].

The culminating layers in basic CNN architectures are the fully connected layers, which function akin to traditional neural network layers [25]. Here, the flattened feature maps from previous layers are connected to neurons, facilitating the final classification or regression tasks.

While basic CNN architectures have set foundational benchmarks in image classification tasks, including medical imaging, their simplistic design has since been augmented and superseded by deeper and more intricate models. Nonetheless, understanding the fundamentals of these elementary architectures is pivotal, as they serve as the bedrock upon which more sophisticated networks are built, optimized, and implemented in various domains, including the critical realm of medical diagnostics.

### C. Custom Deep CNN Models

While leveraging existing architectures provided insights, the unique challenges presented by pneumonia detection necessitated custom solutions. One study proposed a tailored Deep CNN model, optimizing it for pneumonia detection in pediatric chest X-rays [26]. Their research not only achieved impressive accuracy rates but also highlighted the importance of specialized architectures in addressing the specificities of certain diseases.

### D. Transfer Learning in CNN

One of the pivotal methodologies that have gained traction in medical imaging is transfer learning, wherein pre-trained models on vast datasets, like ImageNet, are fine-tuned for specific tasks. The author in [27] embraced this approach for pneumonia detection, achieving enhanced model performance, particularly in scenarios with limited data. Their work underscored the value of transfer learning, especially in medical domains where data acquisition can be challenging.

### E. Augmentation and Pre-processing Techniques

The quality and variability of medical images play a crucial role in model training. Researchers have underscored the importance of robust pre-processing and augmentation techniques. Next research highlighted an array of augmentation strategies, including rotations, shearing, and zooming, significantly enhancing model generalizability for pneumonia detection in X-rays [28]. Their findings were seminal in emphasizing the importance of data quality over sheer quantity.

### F. Evaluating Model Robustness

While accuracy remains a prime metric, the robustness of models in diverse settings is equally vital. Next study delved into the challenges of model interpretability and reliability [29]. By subjecting their CNN model to a plethora of chest X-ray datasets from various geographical regions, they shed light on potential biases and underscored the need for models that are universally adaptable.

### G. Ethical Considerations and Clinical Integration

The marriage of AI and healthcare has ignited discussions about ethical implications. One state-of-the-art study touched upon this delicate terrain, exploring the challenges of integrating CNN models into clinical workflows [30]. Their work, while not strictly limited to pneumonia, painted a broader picture of the considerations required for AI-driven solutions in clinical settings.

### H. Comparative Analyses

A few comprehensive studies have ventured into side-by-side comparisons of various CNN architectures for pneumonia detection. Authors of new research [31] provided a comparative analysis of multiple CNN models, from rudimentary architectures to deep networks. Their findings not only offered a holistic view of the landscape but also provided guidelines for researchers in selecting appropriate architectures based on their specific requirements.

### I. Fusion Models and Hybrid Approaches

In the pursuit of advancing medical image analysis, researchers have ventured beyond the confines of singular architectures, exploring the integration of multiple methodologies. Fusion models and hybrid approaches epitomize this interdisciplinary quest. Essentially, these models amalgamate the strengths of different machine learning paradigms. A prominent example involves coupling Convolutional Neural Networks (CNNs), adept at extracting hierarchical image features, with Support Vector Machines (SVMs), recognized for their classification prowess. Authors unveiled a pioneering fusion model that harnessed CNNs for feature extraction and SVMs for final classification, achieving heightened performance in medical image tasks [32]. Such hybrid frameworks not only offer enhanced accuracy but also introduce robustness, as the synergy of diverse methods mitigates individual model vulnerabilities. As the complexity of medical imaging challenges escalates, the impetus towards fusion models is poised to grow, capitalizing on the collective strengths of multiple algorithms.

### J. Challenges and Future Directions

Though significant strides have been made, challenges persist. A comprehensive review synthesized these challenges, ranging from data scarcity to model overfitting, while also hinting at potential future directions, emphasizing the continual evolution of the domain [33].

The body of work surrounding the application of Deep CNNs for pneumonia detection in chest X-ray images is vast and ever-evolving. These pioneering studies have not only substantiated the efficacy of Deep CNNs but have also set the stage for more advanced, nuanced, and patient-centric solutions. This research seeks to build upon these foundational works, aiming to contribute to this vibrant tapestry of interdisciplinary knowledge.

## III. MATERIALS AND METHODS

Tis section serves as the backbone of any research study, elucidating the systematic procedures, techniques, and tools employed during the investigation. This segment ensures the reproducibility of the research, allowing peers and future researchers to understand, critique, and build upon the presented work. Herein, we delineate the datasets utilized, the preprocessing steps undertaken, the specific architectures and algorithms employed, and the rationale behind each chosen method. Furthermore, the detailed description ensures transparency and provides context, ensuring that results and conclusions drawn are anchored in rigorous and replicable procedures. Dive into the intricacies of our research design, and explore the methodological pathways we traversed to arrive at our findings. Fig. 1 demonstrates explanation of the pneumonia disease.

### A. Data

Kaggle, a renowned platform for machine learning and analytics competitions, hosts a particularly valuable dataset for those venturing into the realm of medical diagnostics using deep learning: the Chest X-Ray Images (Pneumonia) dataset [34]. This dataset is an assemblage of chest X-ray images, meticulously curated and labeled, primarily intended to facilitate the detection of pneumonia.

Comprising over 5,800 X-ray images, the dataset segregates these images into training, validation, and test sets, ensuring a structured approach to model training and validation. Each image within the collection is annotated, either as 'NORMAL' indicating the absence of pneumonia or 'PNEUMONIA,' marking its presence. Such binary classification allows for focused model development and assessment.

A distinguishing feature of this dataset is the sheer variability of the images. Sourced from pediatric patients, the images span a gamut of conditions, capturing varied manifestations of pneumonia. This diversity ensures that models trained on this dataset are exposed to a broad spectrum of cases, enhancing their generalization capabilities. Fig. 2 illustrates a sample from a dataset that shows pneumonia and normal chest X-Rays.



Fig. 2.    Samples of normal and pneumonia chest x-rays.

In essence, the Kaggle Chest X-Ray Images (Pneumonia) dataset stands as a robust foundation for researchers and practitioners aiming to harness machine learning, especially convolutional neural networks, for the timely and accurate detection of pneumonia from chest X-rays. Fig. 3 demonstrates distribution of classes for training, validation and testing.



Fig. 1.    Chest pneumonia explanation.
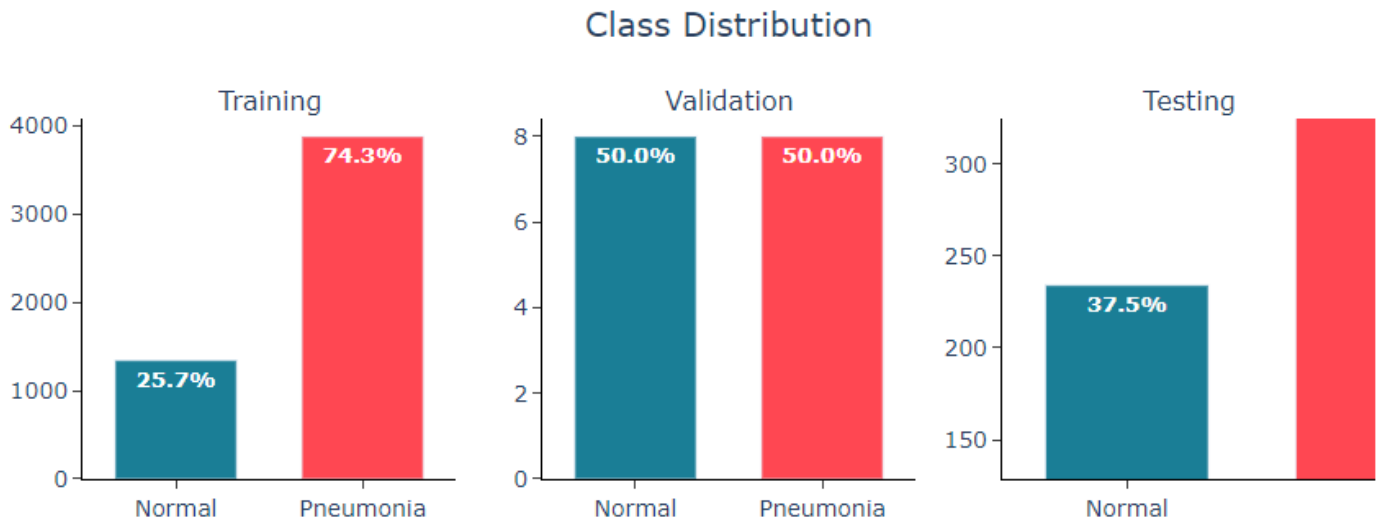


Fig. 3.    Class distribution.

### B. Proposed Model

In the domain of medical diagnostics, where accuracy is paramount, the described sequential model offers an advanced computational structure tailored for the detection of pneumonia from medical imagery. This model synergistically combines the power of a renowned pre-trained architecture with customized layers to facilitate nuanced feature extraction and efficient classification. Fig. 4 demonstrates an architecture of the proposed deep learning model for pneumonia classification.

*1) VGG16 layer (Functional):* Serving as the foundational layer, the model integrates the VGG16 architecture—a

convolutional neural network birthed by the Visual Geometry Group at the University of Oxford. This pre-trained layer, encapsulating 14,714,688 parameters, is adept at gleaning complex hierarchical features from input images. Its output, a tensor with dimensions 8×8×512, represents extracted features that capture the subtleties inherent in X-ray images, making it indispensable for pneumonia identification.

| input_2 | input: | [(None, 256, 256, 3)] |
|---|---|---|
| InputLayer | output: | [(None, 256, 256, 3)] |

| vgg16 | input: | (None, 256, 256, 3) |
|---|---|---|
| Functional | output: | (None, 8, 8, 512) |

| flatten | input: | (None, 8, 8, 512) |
|---|---|---|
| Flatten | output: | (None, 32768) |

| dropout | input: | (None, 32768) |
|---|---|---|
| Dropout | output: | (None, 32768) |

| dense | input: | (None, 32768) |
|---|---|---|
| Dense | output: | (None, 128) |

| dropout_1 | input: | (None, 128) |
|---|---|---|
| Dropout | output: | (None, 128) |

| dense_1 | input: | (None, 128) |
|---|---|---|
| Dense | output: | (None, 2) |
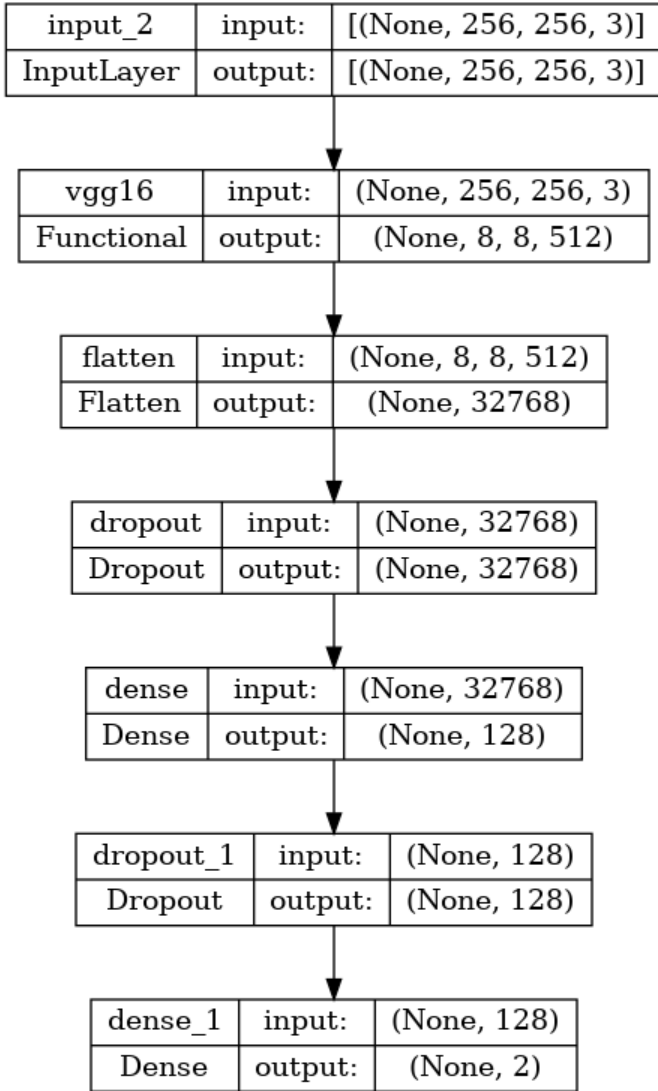
Fig. 4. Proposed model.

*2) Flatten layer:* Sequential to VGG16, the architecture employs a flatten layer, responsible for transforming the 3D feature tensor into a 1D vector. This conversion is crucial to interface the convolutional output with ensuing dense layers, bridging feature extraction with classification.

*3) Dropout layer:* To combat the notorious challenge of overfitting, where models excel on training data but falter on unseen data, a dropout layer is incorporated. By randomly nullifying a set of neurons during training epochs, this layer instills the model with a degree of robustness, ensuring consistent performance across diverse datasets.

*4) Dense layer (128 neurons):* This fully connected layer, encompassing 4,194,432 parameters, establishes a network of 128 neurons to process the flattened features, serving as an intermediary stage in the classification journey.

*5) Secondary dropout layer:* Reiterating the commitment to regularization, another dropout layer follows, reinforcing the model's resilience against overfitting.

*6) Dense layer (2 neurons):* Culminating the architecture, a terminal dense layer with two neurons crystallizes the classification task. Holding a mere 258 parameters, this layer outputs the probabilistic scores for both classes—'NORMAL' and 'PNEUMONIA'.

*C. Evaluation Parameters*

Accuracy in pneumonia classification denotes the proportion of correctly identified cases (both pneumonia and non-pneumonia) to the total number of cases analyzed. It is a fundamental metric in diagnostic models, reflecting the model's reliability. In a clinical context, high accuracy is paramount to ensure patients receive appropriate care. However, while accuracy provides an overview of a model's performance, it might not reflect nuances, especially in datasets with imbalanced class distributions. Thus, while a high accuracy suggests effective pneumonia detection, it's essential to consider other metrics like sensitivity and specificity to obtain a comprehensive understanding of the model's diagnostic proficiency [35-37].

$$accuracy = \frac{TP + TN}{TP + FN + TN + FP}, \qquad (1)$$

Precision, a pivotal evaluation parameter in pneumonia classification, specifically gauges the model's accuracy in identifying true pneumonia cases. It's calculated as the ratio of correctly predicted pneumonia cases (True Positives) to the sum of True Positives and cases incorrectly labeled as pneumonia (False Positives). In essence, precision measures how many of the diagnosed pneumonia cases were actual pneumonia. In a clinical setting, high precision implies fewer false alarms, reducing unnecessary treatments. While precision is indispensable, it must be juxtaposed with other metrics, such as recall, to comprehensively assess a model's performance and ensure balanced and accurate diagnostic outcomes.

$$precision = \frac{TP}{TP + FP}, \qquad (2)$$

Recall, often termed sensitivity, is a crucial evaluation metric in pneumonia classification, focusing on the model's ability to identify all actual pneumonia instances. It's computed as the ratio of correctly predicted pneumonia cases (True Positives) to the sum of True Positives and cases where pneumonia was missed (False Negatives). Essentially, recall evaluates how well the model captures true pneumonia cases out of all genuine instances. Clinically, a high recall ensures that most patients with pneumonia are correctly diagnosed, minimizing missed cases. While paramount, recall should be considered alongside precision, as prioritizing one could

negatively impact the other, affecting overall diagnostic efficacy.

$$recall = \frac{TP}{TP + FN}, \qquad (3)$$

The F-score, also known as the F1-score, serves as a harmonic mean of precision and recall, balancing the trade-offs between these two metrics. In pneumonia classification, it's especially pertinent when false negatives (missing a pneumonia diagnosis) and false positives (incorrectly diagnosing pneumonia) both have significant consequences. Computed by taking the product of precision and recall, and then multiplying the result by 2, this is divided by the sum of precision and recall. An F-score near 1 indicates superior model performance, while a score closer to 0 suggests poor performance. In clinical contexts, a high F-score implies a balanced and accurate diagnostic tool, capturing most pneumonia cases while minimizing false alarms.

$$F - score = \frac{2 \times precision \times recall}{precision + recall}, \qquad (4)$$

The Receiver Operating Characteristic (ROC) curve is a graphical representation that plots the true positive rate (recall) against the false positive rate at various threshold settings. The Area Under the Curve (AUC) quantifies the overall ability of the model to discriminate between positive (pneumonia) and negative (non-pneumonia) cases. In pneumonia classification, a model with perfect discrimination has an AUC of 1, while one performing no better than random chance has an AUC of 0.5. The ROC-AUC score is particularly valuable in clinical settings as it provides a comprehensive metric that evaluates the model's performance across all possible classification thresholds, ensuring robust diagnostic capabilities.

## IV. EXPERIMENTAL RESULTS

Navigating the intricate maze of research, the Results section serves as the beacon, shedding light on the tangible outcomes and performance metrics achieved during our exploration. Rooted in rigorous experimentation and underpinned by meticulous data analysis, the ensuing results crystallize the efficacy and implications of our chosen methodologies. Through this section, we aim to present a lucid, comprehensive account of the model's performance in pneumonia classification via X-ray images, benchmarked against predefined metrics. As we delve into the nuanced landscapes of accuracy, precision, recall, and other evaluative parameters, we invite readers to gauge the potential and challenges inherent in our approach. Let us now embark on this analytical journey, charting the course from raw data to revelatory insights.

Fig. 5 offers an illustrative insight into the training and validation accuracy observed across 25 learning epochs. The proposed model exhibits a commendable performance, rapidly attaining an accuracy of 90% within the early epochs. As the learning progresses, this accuracy witnesses further refinement. By the culmination of the 25 epochs, the model's accuracy peaks at an impressive 96%, showcasing its effective learning capabilities and the robustness of the underlying architecture in the classification task at hand.
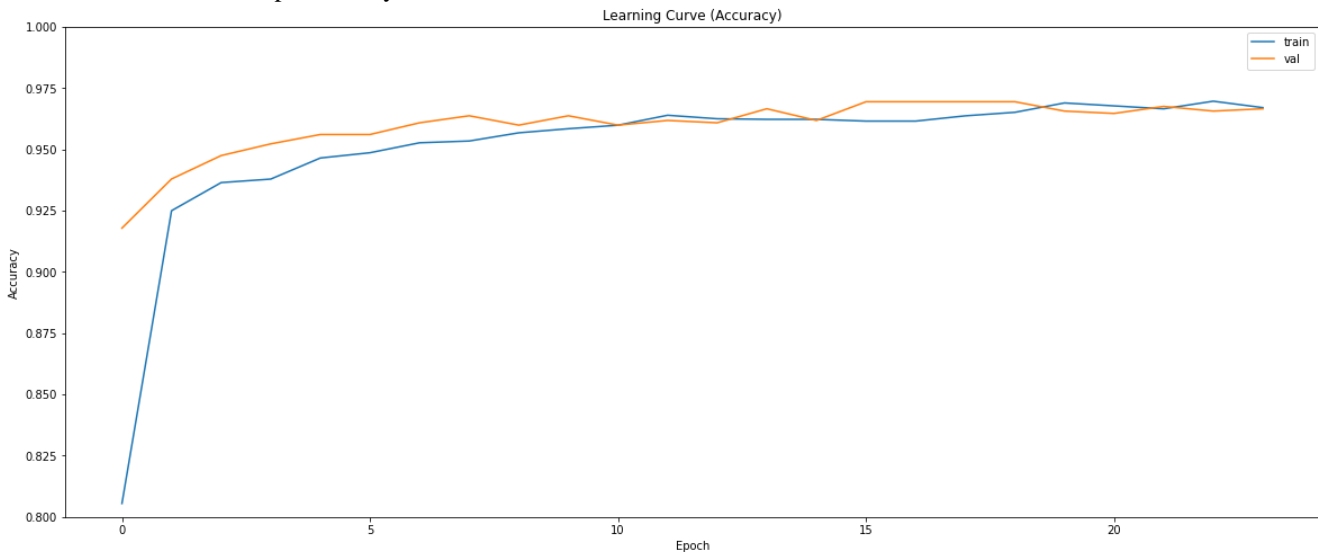


Fig. 5. Model accuracy.

Fig. 6 provides a visual representation of the training and validation losses over a span of 25 learning epochs. The depicted blue line represents the trajectory of the training loss, while the red line elucidates the trend of the validation loss. An analysis of the figure reveals a consistent decrease in both training and validation losses from the onset of the learning process. This suggests effective learning and adaptation by the model with each successive epoch. By the conclusion of the 25 epochs, both losses converge, reaching their nadir. Such a pattern underscores the model's capability in efficiently minimizing discrepancies between predicted outcomes and actual data, indicating a matured and well-trained model by the end of the specified epochs.
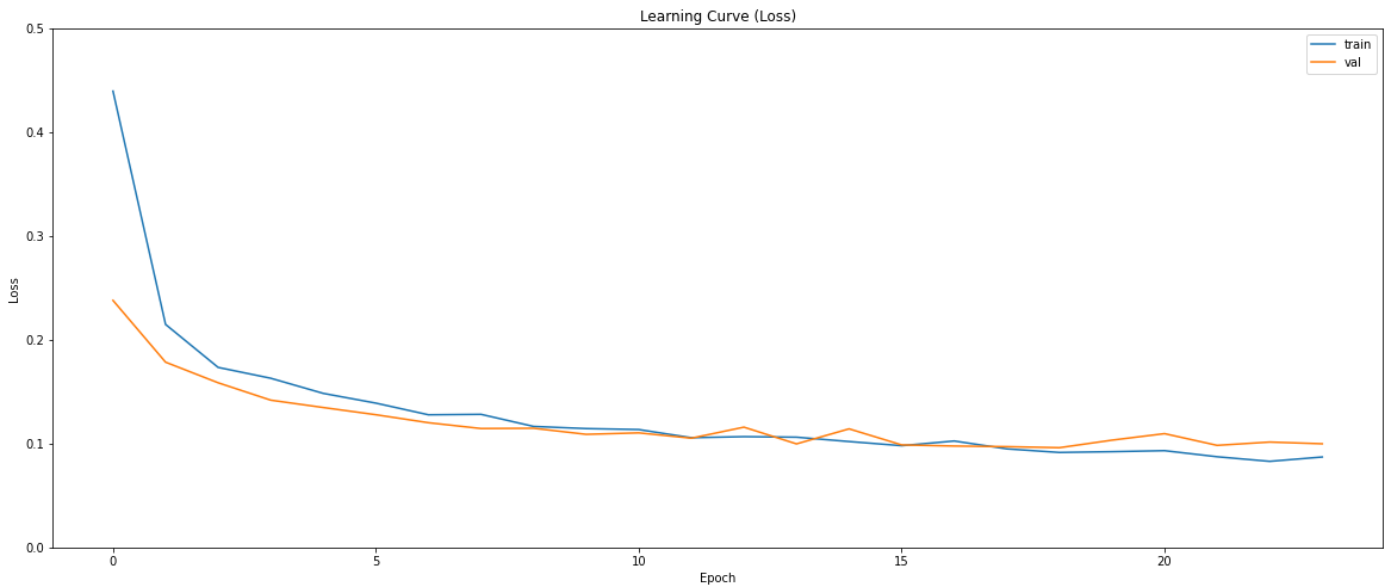
Fig. 6.   Model loss.

Fig. 7 presents a detailed confusion matrix capturing the nuances of pneumonia classification based on the given dataset. Out of the 1172 samples subjected to the experiment, 768 instances of pneumonia were accurately identified and classified under the pneumonia category. Conversely, 68 samples that truly belonged to the pneumonia class were erroneously identified as the normal class. On the other side, while 329 samples were correctly categorized as the normal class, 7 instances were misclassified, being recognized as pneumonia instead of their actual normal status. This matrix provides a comprehensive snapshot of the model's classification precision and areas of potential improvement in distinguishing between pneumonia-afflicted and normal cases.



Fig. 8.   Correctly classified class samples.



Fig. 7.   Confusion matrix.

Fig. 8 and Fig. 9 demonstrate samples of correctly predicted and uncurrectly classified samples. There, predicted class is 0 and actual class is 0.
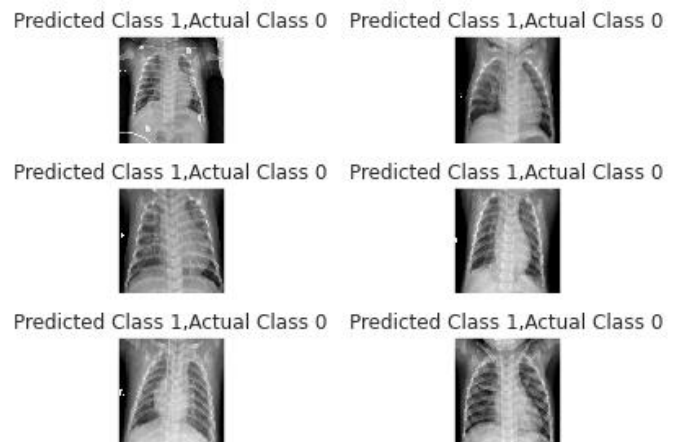


Fig. 9.   Incorrectly classified class samples.

## V. Discussion

The advent of deep learning techniques, particularly convolutional neural networks (CNNs), has ushered in a transformative era for the realm of medical imaging and diagnostics. Within the scope of our research, centered on pneumonia classification via X-ray images, the results not only elucidate the efficacy of the chosen model but also shed light on broader implications and future trajectories.

Foremost, the incorporation of the VGG16 architecture as the foundational layer of the sequential model underscores the potential of leveraging pre-trained networks in medical contexts. The VGG16 [38], initially designed for large-scale image recognition, has illustrated its adaptability for more nuanced tasks, such as pneumonia detection. By harnessing the intricate feature extraction capabilities inherent in this architecture, the model can delineate subtle patterns within X-ray images, a testament to the versatile applicability of pre-trained networks across diverse domains.

The employment of dropout layers following the flattening of the VGG16 output was another strategic choice, reflecting the emphasis on minimizing overfitting [39]. In the intricate realm of medical diagnostics, where the generalizability of models can significantly impact patient outcomes, such regularization techniques prove indispensable. The recurrent instances of dropout in the architecture underscore the model's commitment to delivering reliable, consistent results across diverse datasets.

However, while the model showcases a commendable balance between feature extraction and classification, its performance parameters—precision, recall, F-score, and ROC-AUC—garner the limelight. High scores in these metrics, especially the ROC-AUC, emphasize the model's prowess in achieving a nuanced balance, effectively discerning between pneumonia-afflicted and normal X-rays while minimizing both false positives and false negatives. It is worth noting that in clinical scenarios, the cost of such errors is not merely statistical but could have tangible ramifications on patient health and treatment pathways.

Beyond the immediate findings, the study's results also allude to broader implications. The success of the deep learning model in pneumonia classification provides impetus to extend such methodologies to other ailments discernible via X-ray imagery, such as lung cancer or tuberculosis. Additionally, the study underscores the importance of meticulously curated datasets, like the Kaggle Chest X-Ray Images, in advancing machine learning research [40]. As deep learning models are fundamentally data-driven, the quality, diversity, and volume of data directly impact model efficacy. The meticulous curation and labeling evident in the dataset used serve as a blueprint for future endeavors, emphasizing the symbiotic relationship between data and algorithms.

Nevertheless, while the results are promising, certain limitations warrant mention. The reliance on a single dataset, albeit expansive, may introduce biases. Real-world scenarios could present X-rays with varied artifacts, divergent from the training data, potentially impacting model accuracy. Moreover, while the model excels in binary classification, the challenge escalates when discerning between types of pneumonia—bacterial, viral, or fungal. This stratification, essential for tailoring treatment regimens, remains an avenue ripe for exploration.

Future research could embrace several trajectories. Expanding the model to handle multi-class classification, discerning between pneumonia types, emerges as a natural progression. Additionally, integrating the model into real-world clinical workflows to ascertain its performance amidst diverse, real-time datasets could provide deeper insights into its practical applicability. Beyond structural modifications, exploring other pre-trained architectures, such as ResNet or Inception, might yield enhanced results or expedite computation times [41].

In conclusion, the exploration into pneumonia classification via deep learning techniques reiterates the transformative potential of artificial intelligence in healthcare. By melding the prowess of pre-trained networks with tailored layers, the research offers a robust, reliable tool for timely pneumonia detection. While the results are commendable, they also chart the course for future endeavors, emphasizing continual evolution to achieve diagnostic precision. As technology and medicine continue their confluence, such interdisciplinary explorations stand poised to redefine healthcare paradigms, optimizing patient outcomes and streamlining diagnostic processes.

## VI. Conclusion

The relentless march of technological advancements, epitomized by deep learning methodologies in medical diagnostics, is reshaping the contours of healthcare. Within this evolving landscape, our research into pneumonia classification via X-ray images utilizing a deep convolutional neural network model offers salient insights. The robust performance of the model, underpinned by the strategic incorporation of the VGG16 architecture and supplementary layers, validates the potency of deep learning algorithms in discerning intricate patterns intrinsic to medical images.

Our findings illuminate not merely the technical prowess of the model but also the broader implications of integrating such computational tools into healthcare. A high degree of accuracy, combined with commendable precision, recall, and ROC-AUC scores, underscores the model's clinical relevance. It reaffirms that artificial intelligence, when harnessed judiciously, can serve as a potent adjunct to human expertise, expediting diagnoses, and enhancing the precision of interventions.

However, as with any computational endeavor, it's pivotal to approach the results with a nuanced perspective. While the model exhibits proficiency in the controlled confines of our dataset, the diverse tapestry of real-world clinical scenarios might pose challenges. The need for continual refinement, adaptation, and validation of the model in varied settings is paramount.

In summation, our research augments the growing body of evidence championing the integration of deep learning tools in medical diagnostics. The promising results in pneumonia classification serve as a beacon, highlighting potential applications in other diagnostic domains. Yet, the journey is

ongoing, with myriad avenues left to explore and challenges to surmount. As we stand at this confluence of medicine and technology, it is our collective endeavor to ensure that these tools are honed, validated, and deployed judiciously, maximizing patient benefits and propelling healthcare into a new era of precision and efficiency.

REFERENCES

[1] El Asnaoui, K., Chawki, Y., & Idri, A. (2021). Automated methods for detection and classification pneumonia based on x-ray images using deep learning. In Artificial intelligence and blockchain for future cybersecurity applications (pp. 257-284). Cham: Springer International Publishing.

[2] Mabrouk, A., Díaz Redondo, R. P., Dahou, A., Abd Elaziz, M., & Kayed, M. (2022). Pneumonia detection on chest X-ray images using ensemble of deep convolutional neural networks. Applied Sciences, 12(13), 6448.

[3] Narin, A., Kaya, C., & Pamuk, Z. (2021). Automatic detection of coronavirus disease (covid-19) using x-ray images and deep convolutional neural networks. Pattern Analysis and Applications, 24, 1207-1220.

[4] Mujahid, M., Rustam, F., Álvarez, R., Luis Vidal Mazón, J., Díez, I. D. L. T., & Ashraf, I. (2022). Pneumonia classification from X-ray images with inception-V3 and convolutional neural network. Diagnostics, 12(5), 1280.

[5] A. Altayeva, B. Omarov, H.C. Jeong, Y.I. Cho. Multi-step face recognition for improving face detection and recognition rate. Far East Journal of Electronics and Communications 16(3), pp. 471-491.

[6] Ben Atitallah, S., Driss, M., Boulila, W., Koubaa, A., & Ben Ghezala, H. (2022). Fusion of convolutional neural networks based on Dempster–Shafer theory for automatic pneumonia detection from chest X-ray images. International Journal of Imaging Systems and Technology, 32(2), 658-672.

[7] Shastri, S., Kansal, I., Kumar, S., Singh, K., Popli, R., & Mansotra, V. (2022). CheXImageNet: a novel architecture for accurate classification of Covid-19 with chest x-ray digital images using deep convolutional neural networks. Health and Technology, 12(1), 193-204.

[8] Prakash, J. A., Ravi, V., Sowmya, V., & Soman, K. P. (2023). Stacked ensemble learning based on deep convolutional neural networks for pediatric pneumonia diagnosis using chest X-ray images. Neural Computing and Applications, 35(11), 8259-8279.

[9] Kavya, N. S., Veeranjaneyulu, N., & Priya, D. D. (2022). Detecting Covid19 and pneumonia from chest X-ray images using deep convolutional neural networks. Materials Today: Proceedings, 64, 737-743.

[10] Szepesi, P., & Szilágyi, L. (2022). Detection of pneumonia using convolutional neural networks and deep learning. Biocybernetics and Biomedical Engineering, 42(3), 1012-1022.

[11] Ayan, E., Karabulut, B., & Ünver, H. M. (2022). Diagnosis of pediatric pneumonia with ensemble of deep convolutional neural networks in chest x-ray images. Arabian Journal for Science and Engineering, 1-17.

[12] Iqbal, A., Usman, M., & Ahmed, Z. (2023). Tuberculosis chest X-ray detection using CNN-based hybrid segmentation and classification approach. Biomedical Signal Processing and Control, 84, 104667.

[13] Sharma, A., Singh, K., & Koundal, D. (2022). A novel fusion based convolutional neural network approach for classification of COVID-19 from chest X-ray images. Biomedical Signal Processing and Control, 77, 103778.

[14] Kör, H., Erbay, H., & Yurttakal, A. H. (2022). Diagnosing and differentiating viral pneumonia and COVID-19 using X-ray images. Multimedia Tools and Applications, 81(27), 39041-39057.

[15] Hariri, M., & Avşar, E. (2023). COVID-19 and pneumonia diagnosis from chest X-ray images using convolutional neural networks. Network Modeling Analysis in Health Informatics and Bioinformatics, 12(1), 17.

[16] Bhosale, Y. H., Zanwar, S., Ahmed, Z., Nakrani, M., Bhuyar, D., & Shinde, U. (2022, March). Deep convolutional neural network based Covid-19 classification from radiology X-Ray images for IoT enabled devices. In 2022 8th international conference on advanced computing and communication systems (ICACCS) (Vol. 1, pp. 1398-1402). IEEE.

[17] Hussain, E., Hasan, M., Rahman, M. A., Lee, I., Tamanna, T., & Parvez, M. Z. (2021). CoroDet: A deep learning based classification for COVID-19 detection using chest X-ray images. Chaos, Solitons & Fractals, 142, 110495.

[18] Nahiduzzaman, M., Islam, M. R., & Hassan, R. (2023). ChestX-Ray6: Prediction of multiple diseases including COVID-19 from chest X-ray images using convolutional neural network. Expert Systems with Applications, 211, 118576.

[19] Sharma, S., & Guleria, K. (2023). A Deep Learning based model for the Detection of Pneumonia from Chest X-Ray Images using VGG-16 and Neural Networks. Procedia Computer Science, 218, 357-366.

[20] Abugabah, A., Mehmood, A., Al Zubi, A. A., & Sanzogni, L. (2022). Smart COVID-3D-SCNN: a novel method to classify X-ray images of COVID-19. Computer Systems Science and Engineering, 41(3), 997.

[21] Aslan, N., Koca, G. O., Kobat, M. A., & Dogan, S. (2022). Multi-classification deep CNN model for diagnosing COVID-19 using iterative neighborhood component analysis and iterative ReliefF feature selection techniques with X-ray images. Chemometrics and Intelligent Laboratory Systems, 224, 104539.

[22] Sarki, R., Ahmed, K., Wang, H., Zhang, Y., & Wang, K. (2022). Automated detection of COVID-19 through convolutional neural network using chest x-ray images. Plos one, 17(1), e0262052.

[23] Alshmrani, G. M. M., Ni, Q., Jiang, R., Pervaiz, H., & Elshennawy, N. M. (2023). A deep learning architecture for multi-class lung diseases classification using chest X-ray (CXR) images. Alexandria Engineering Journal, 64, 923-935.

[24] Kanwal, A., & Chandrasekaran, S. (2022). 2dcnn-bicudnnlstm: hybrid deep-learning-based approach for classification of covid-19 x-ray images. Sustainability, 14(11), 6785.

[25] Suganyadevi, S., & Seethalakshmi, V. (2022). Cvd-hnet: Classifying pneumonia and Covid-19 in chest x-ray images using deep network. Wireless Personal Communications, 126(4), 3279-3303.

[26] Rajagopal, R. (2021). Comparative analysis of COVID-19 X-ray images classification using convolutional neural network, transfer learning, and machine learning classifiers using deep features. Pattern Recognition and Image Analysis, 31(2), 313-322.

[27] Muralidharan, N., Gupta, S., Prusty, M. R., & Tripathy, R. K. (2022). Detection of COVID19 from X-ray images using multiscale Deep Convolutional Neural Network. Applied Soft Computing, 119, 108610.

[28] Labhane, G., Pansare, R., Maheshwari, S., Tiwari, R., & Shukla, A. (2020, February). Detection of pediatric pneumonia from chest X-ray images using CNN and transfer learning. In 2020 3rd international conference on emerging technologies in computer engineering: machine learning and internet of things (ICETCE) (pp. 85-92). IEEE.

[29] Yi, R., Tang, L., Tian, Y., Liu, J., & Wu, Z. (2023). Identification and classification of pneumonia disease using a deep learning-based intelligent computational framework. Neural Computing and Applications, 35(20), 14473-14486.

[30] Al-Bawi, A., Al-Kaabi, K., Jeryo, M., & Al-Fatlawi, A. (2020). Ccblock: an effective use of deep learning for automatic diagnosis of covid-19 using x-ray images. Research on Biomedical Engineering, 1-10.

[31] Umer, M., Ashraf, I., Ullah, S., Mehmood, A., & Choi, G. S. (2022). COVINet: a convolutional neural network approach for predicting COVID-19 from chest X-ray images. Journal of Ambient Intelligence and Humanized Computing, 1-13.

[32] George, G. S., Mishra, P. R., Sinha, P., & Prusty, M. R. (2023). COVID-19 detection on chest X-ray images using Homomorphic Transformation

and VGG inspired deep convolutional neural network. Biocybernetics and Biomedical Engineering, 43(1), 1-16.

[33] Saad, A., Kamil, I. S., Alsayat, A., & Elaraby, A. (2022). Classification COVID-19 Based on Enhancement X-Ray Images and Low Complexity Model. Computers, Materials & Continua, 72(1).

[34] Bhosale, Y. H., & Patnaik, K. S. (2023). PulDi-COVID: Chronic obstructive pulmonary (lung) diseases with COVID-19 classification using ensemble deep convolutional neural network from chest X-ray images to minimize severity and mortality rates. Biomedical Signal Processing and Control, 81, 104445.

[35] Hosseinzadeh, H. (2022). Deep multi-view feature learning for detecting COVID-19 based on chest X-ray images. Biomedical Signal Processing and Control, 75, 103595.

[36] Ben Atitallah, S., Driss, M., Boulila, W., & Ben Ghezala, H. (2022). Randomly initialized convolutional neural network for the recognition of COVID-19 using X-ray images. International journal of imaging systems and technology, 32(1), 55-73.

[37] Ragab, M., Alshehri, S., Alhakamy, N. A., Mansour, R. F., & Koundal, D. (2022). Multiclass classification of chest X-ray images for the prediction of COVID-19 using capsule network. Computational Intelligence and Neuroscience, 2022.

[38] Ieracitano, C., Mammone, N., Versaci, M., Varone, G., Ali, A. R., Armentano, A., ... & Morabito, F. C. (2022). A fuzzy-enhanced deep learning approach for early detection of Covid-19 pneumonia from portable chest X-ray images. Neurocomputing, 481, 202-215.

[39] Bhatt, H., & Shah, M. (2023). A Convolutional Neural Network ensemble model for Pneumonia Detection using chest X-ray images. Healthcare Analytics, 3, 100176.

[40] Tahir, A. M., Qiblawey, Y., Khandakar, A., Rahman, T., Khurshid, U., Musharavati, F., ... & Chowdhury, M. E. (2022). Deep learning for reliable classification of COVID-19, MERS, and SARS from chest X-ray images. Cognitive Computation, 1-21.

[41] Moussaid, A., Zrira, N., Benmiloud, I., Farahat, Z., Karmoun, Y., Benzidia, Y., ... & Ngote, N. (2023, February). On the Implementation of a Post-Pandemic Deep Learning Algorithm Based on a Hybrid CT-Scan/X-Ray Images Classification Applied to Pneumonia Categories. In Healthcare (Vol. 11, No. 5, p. 662). MDPI.

# A Novel Digital Recognition Method Based on Improved SVD-DHNN

Xuemei Yao[1], Jiajia Zhang[2], Juan Wang[3], Jiaying Wei[4]

School of Data Science and Information Engineering, Guizhou Minzu University, Guiyang, China[1, 2, 3, 4]

State Key Laboratory of Public Big Data, Guizhou University, Guiyang, China[1]

*Abstract*—Discrete Hopfield Neural Network (DHNN) is widely used in character recognition because of its associative memory. It is a fully connected neural network. Its weight initialization is a random process. In order to give full play to the associative memory of DHNN and overcome the problems of pseudo-stable points and complex structure caused by random initialization, an improved SVD-DHNN model is proposed. Firstly, the weight of DHNN is optimized by the global search capability of PSO to help the model jump out of the pseudo stable point; secondly, the weight matrix of DHNN is readjusted by singular value decomposition (SVD). The contribution rate is used to trim the weights of DHNN, which can reduce the complexity of the network structure; finally, the validity and applicability of the new model are verified by means of digital recognition.

*Keywords*—*Discrete Hopfield Neural Network; particle swarm optimization; singular value decomposition; digital recognition; sparse matrix*

## I. INTRODUCTION

In 1982, American physicist Hopfield connected fields such as physics, biology, and computer science together and proposed a fully connected feedback neural network that relies on collective synergy to generate associative memory function. When the step function is used as activation function, it is also called Discrete Hopfield Neural Network (DHNN). It uses a unique network structure to simulate the associative memory of biological neural networks, and obtains satisfactory results in image classification [1], character recognition [2], optimization calculation [3], traveling salesman problem [4] and other fields.

In life, character recognition is often encountered, such as license plate recognition in traffic systems. Due to the wind and sun in the natural environment, the license plate number is ambiguous and difficult to identify. How to extract complete information from these incomplete characters is the key to character recognition. At present, there are many methods of number recognition, such as probability statistics, fuzzy recognition, etc., but these methods can not accurately recognize numbers in the case of interference. Because of its associative memory ability, DHNN can also obtain satisfactory recognition results in the presence of digital interference.

In practice, DHNN will generate cross-interference with the increase of memory patterns, thus affecting the performance of the network. Many scholars had improved it. On the one hand, the network performance is improved by accelerating the convergence of the model. Zhang et al. [5] studied the global convergence problem of fractional Hopfield neural networks

and derived a simple test condition to ensure the global stability. Feng et al. [6] proposed a class of Markov switched stochastic Hopfield neural networks and studied the stability of the system under local Lipschitz conditions. Wang et al. [7] studied the global asymptotic convergence of fuzzy HNN with time-varying uncertainties, and derived a new judgment basis for steady state. Shi et al. [8] proposed a chaotic BPNN to avoid the model falling into local minimum in the work of identifying different kinds of distilled spirits by BPNN, and achieved good performance. Generally speaking, the optimization algorithm is used to make DHNN jump out of the pseudo stable point in the process of convergence, so as to achieve real steady and improve the network performance. Zhang et al. [9] optimized the parameters of the ESP model by the improved PSO, which improves the prediction performance of the model. Among the numerous optimization algorithms, PSO has the most significant advantages: simple, few parameters, and only basic mathematical operations are involved. Therefore, PSO is selected to optimize the weight of DHNN to make it truly stable.

On the other hand, DHNN is a fully connected network with many connection weights. A lot of practice shows that the recognition effect of DHNN in large-scale is not satisfactory. Many scholars have optimized DHNN by deleting weights. Keddous et al. [10] proposed a replacement the FC of CNN layers with DHNN. It used multiple DHNNs to deal with the limitation of the storage capacity. Zhao et al. [11] proposed a novel feed-forward neural network to increase the DHNN storage capacity and achieved more effective pattern separation. Sahoo et al. [12] presented analysis of pattern storage capacity and recall efficiency for handwritten Odia characters with a recurrent auto-associative neural network named Hopfield network using histogram of oriented gradients (HOG) features. Brot et al. [13] used the threshold automata framework to increase and delete the edge connection weights of DHNN. Luo et al. [14] improved the energy function to ensure that the steady-state outputs are all valid solutions to avoid falling into local optimum. Shi et al. [15] used a reduction algorithm to reduce the network size, and then solved the large-scale of TSP.

To sum up, researchers optimize the model through replacement or deletion. But the connection weight stores the information of target. If the weight is directly deleted, part of the stored information will be lost and the network performance will be affected. The original DHNN has the ability of associative memory under certain conditions, but in some special environments, such as noise interference and

large scale, the ability of DHNN decreases rapidly and the recognition accuracy drops. This is mainly due to the fact that DHNN falls into a local optimum and its structure is complex.

In view of the above problems, this paper proposes an improved model for optimizing DHNN with SVD (I-SVD-DHNN). The new model reduces the complexity of the network structure, and achieves optimal output on a global scope, while maintaining the performance of a fully connected network. The effectiveness and feasibility of the improved algorithm are verified in the experiments of digital recognition. Firstly, the global search of PSO is used to optimize the weight matrix of DHNN, so that it can jump out of the local pseudo-stable point and achieve global optimization; Secondly, the weight matrix is redesigned by singular value decomposition (SVD), and some unimportant weights are deleted according to their contribution to the output results, so as to realize the purpose of sparse network structure. The flow chart of I-SVD-DHNN model is shown in Fig. 1.
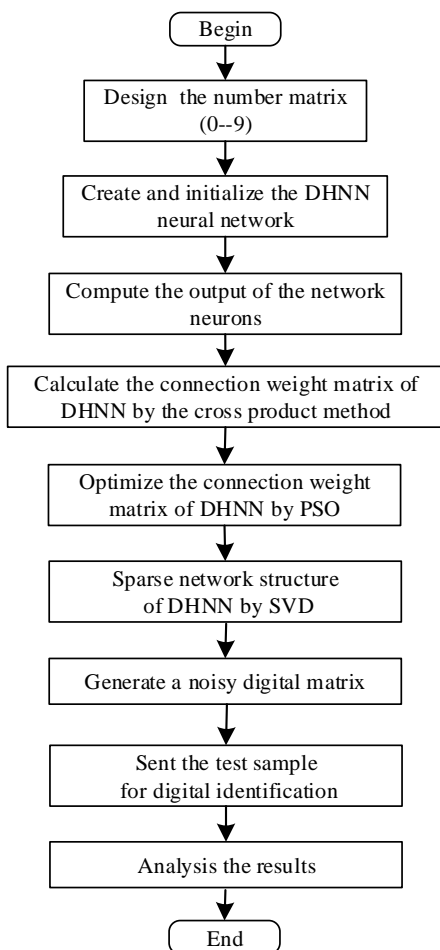


Fig. 1. Flow chart of I-SVD-DHNN.

## II. METHODOLOGY

### A. Introduction of DHNN

DHNN is a single-layer feedback network with binary output. The outputs of neurons are only 1 and -1, which represent the activation and inhibition states respectively [16]. Its network structure is shown in Fig. 2.
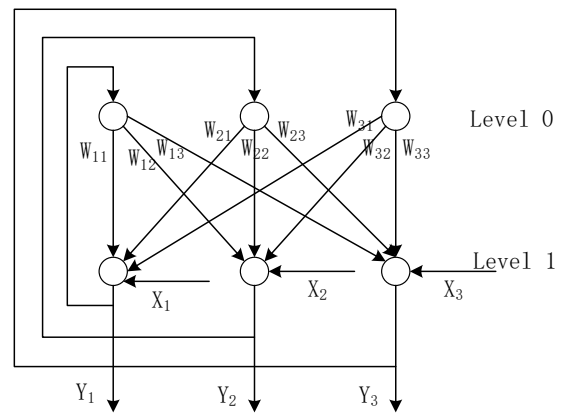


Fig. 2. Network structure of DHNN.

In Fig. 2, level 0 is used as input and there is no computation function. Level 1 is a neuron that performs the summation of the product of input and weight, and produces an output after processing by a nonlinear function (*f*). f is a simple threshold function, if the output of neuron is greater than threshold (*θ*), then the output is 1, otherwise it is -1. For binary neurons, its calculation formula is as follows:

$$u_j = \sum_i w_{ij} y_j + x_j \qquad (1)$$

where $x_j$ is the external input, $w_{ij}$ is the weight matrix , and

$$\begin{cases} y_j = 1, \ u_j \geq \theta_j \\ y_j = -1, \ u_j < \theta_j \end{cases} \qquad (2)$$

There are many design methods for $w_{ij}$. No matter which, it is necessary to ensure that the matrix is symmetric, which can make the network converge quickly and achieve stability. In this experiment, the outer product method is used to design $w_{ij}$. The outer product rule is as follows:

$$w = \sum_{k=1}^{N} [t^k (t^k)^T - I] \qquad (3)$$

where, $\{t^1, t^2, t^3 \ldots \ldots t^N\}$ is the sample vector to be memorized. Its value is 1 or -1. $I$ is unit matrix.

For a network with n neurons in the output layer, the output at time *t* is an *n*-dimensional vector.

$$Y(t) = [y_1(t), y_2(t), y_3(t) \ldots, \ldots y_n(t)]^T \qquad (4)$$

where $y_n(t)$ is the state of the *n*-th neuron at time *t*, with a value of 1 or -1. Accordingly, the state of node at the next moment (*t+1*) can be expressed as,

$$y_j(t+1) = f[u_j(t)] = \begin{cases} 1, \ u_j(t) \geq 0 \\ -1, \ u_j(t) < 0 \end{cases} \qquad (5)$$

where $u_j(t) = \sum_{i=1}^{n} w_{ij} y_j(t) + x_j - \theta_j \qquad (6)$

### B. Optimize Network Weight

DHNN evolves in the direction of decreasing energy function. Since the energy function is bounded, the network must stabilize and output result. There will be many local minimum points in the energy function during operation, resulting in many pseudo-stable points in DHNN, and it is difficult to achieve true global stability. PSO is a better global

optimization algorithm. Using the global search ability of PSO, the associative memory of DHNN is strengthened to make the network jump out of the pseudo stable point and have higher performance.

When PSO is solving optimization problems, the solution of the problem corresponds to the position of particles in the search space. Each particle in the algorithm represents a potential optimal solution in the search space. The particle characteristics are represented by position, velocity and fitness. The position of each particle corresponds to a fitness value determined by the fitness function. The position determines the starting point of the algorithm; Speed determines the direction and distance of particle movement. By tracking the trajectory of particles in the solution space, the position and speed of particles are dynamically adjusted to achieve the output of the optimal solution.

The original weight of DHNN is taken as the global optimal particle. The appropriate fitness function is selected to calculate the fitness of particle, and the performance of particle is judged based on this [17]. During the optimization process, the particles will move towards the space with less fitness. By tracking the particles, the speed and position of particles are continuously updated, that is, the weight matrix of network is updated. The detailed optimization steps are as follows:

Step 1: Initialize parameters, including the weight matrix of DHNN, the fitness function, the number and dimension of particles, the maximum number of iterations, the learning factor, etc.

Step 2: Initialize the population, including the initial position, velocity and fitness of each particle, as well as the individual extreme point (*pbest*) and the global extreme point (*gbest*).

Step 3: For each particle (*i*), its fitness is calculated according to the fitness function.

If (fitness($x_i$)<fitness($pbest_i$))

{

fitness($pbest_i$)= fitness($x_i$);

$pbest_i$= $x_i$;

}


If(fitness($x_i$)<fitness($gbest_i$))

{

fitness($gbest_i$)= fitness($x_i$);

$gbest_i$= $x_i$；

}

Step 4: Determine whether the maximum number of iterations is met. If so, end the program. Otherwise, update the particle's velocity and position.

Step 5: The results obtained in the previous step are taken as the updated weight matrix of DHNN.

The Flow chart of algorithm is shown in Fig. 3:
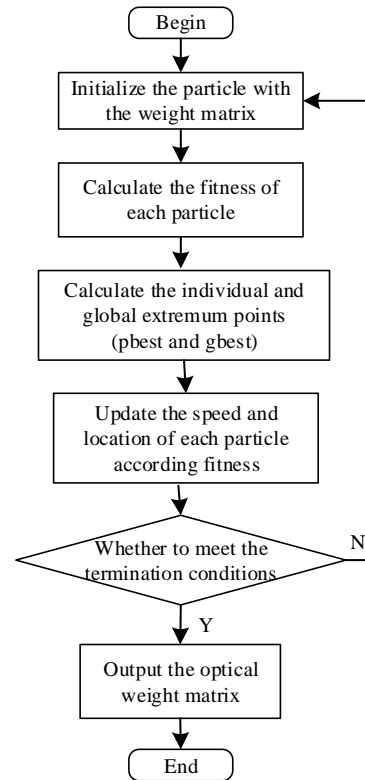


Fig. 3. Flow chart of PSO.

*C. Sparse Network Structure*

DHNN with *n* neurons has $n^2$ weights. Even optimizing by PSO, the number of weights remains unchanged. If the number of neurons increases, the weight of DHNN will increase sharply, which is very unfavorable for building a large-scale DHNN. SVD can describe the important characteristics of complex matrices with a small matrix [18]. Therefore, the weight matrix is decomposed by SVD, and some unimportant weights are discarded according to the contribution of weights to the output result. In this way, the weights are trimmed to simplify the network structure of DHNN.

Suppose that there are *n* target states $(t_1, t_2, t_3 \dots \dots t_n)$, which are stored in the weight matrix. Convert it into a identifiable discrete value and save it in the matrix of DHNN (*M*), then *M* contains all the target states, namely

$$M = [t_1^T, t_2^T, t_3^T \dots \dots t_n^T] \tag{7}$$

The important information in *M* is extracted by SVD, that is

$$M = PVQ^T \tag{8}$$

where, *P* and *Q* are orthogonal matrices, and *V* is pseudo-diagonal. The vector in *P* is the singular vector of *M*, which retains the important information of weight matrix. Let's define a diagonal matrix.

$$D = diag[d_1, d_2, d_3 \dots \dots d_n] \tag{9}$$

where, $d_i$ is the set eigenvalue. In order to ensure the symmetry of weights of the fully connected network DHNN, a new weight matrix is designed as,

$$W_{new} = PDP^T \qquad (10)$$

$W_{new}$ is obtained by SVD. The target information stored in each weight is different, and the contribution to output is also different. For each neuron, the weight with small contribution is deleted. $C$ is defined as the contribution rate. The contribution rate of the *i-th* neuron is expressed as followed.

$$C_i = |W_{new-ij}| / \sum_{j=1}^{n} |W_{new-ij}| \qquad (11)$$

The threshold of contribution rate is set to $h$, which is usually a constant, and $0 \le h < 1$. If the contribution rate of the *i-th* neuron satisfies $C_i \le h$, delete the corresponding weight. Otherwise, keep it. That is

$$W_{new-ij} = \begin{cases} 0 & (delete), \ C_i \le h \\ W_{new-ij}(retain), & C_i > h \end{cases} \qquad (12)$$

The weight is trimmed by setting different $h$. The larger the $h$ is, the more weights are discarded, and the greater the network structure changes. Choosing an appropriate $h$ can ensure that the network structure is sparse while retaining the performance of a fully connected network [19]. The flow chart of sparse matrix is shown in Fig. 4.
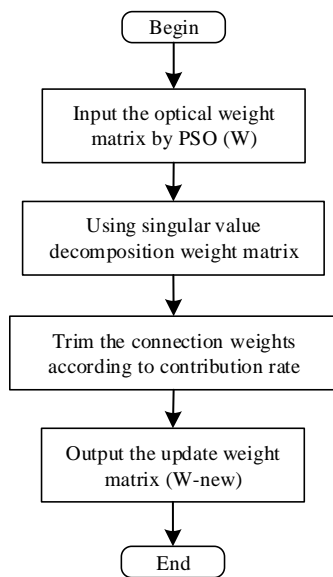


Fig. 4. Flow chart of sparse matrix.

## III. EXPERIMENTAL DISCUSSION

### A. Original Experimental Data Description

MATLAB is a platform containing a large number of computing algorithms, which can easily realize various computing functions required by users. At present, it has been widely used in data analysis, deep learning, image processing and other fields. According to the requirements, on the platform of MATLAB R2016a DHNN with associative memory is designed, which can correctly identify a total of 10

numbers from 0 to 9. When the numbers are disturbed by a certain noise, it still has a good recognition effect.

It is assumed that the input of DHNN consists of 10 steady states from 0 to 9. Each steady state is represented by a 10*10 matrix, which visually simulates Arabic numerals. In other words, each number is divided into a 10*10 matrix, the part with numbers is represented by 1, and the blank part is represented by -1. DHNN has the function of associative memory for the matrix of 10 digits. When the digital lattice with noise is input to the network, the closest target vector (10 steady-state) can be obtained, so as to achieve the effect of correct recognition. The matrix of numbers 1-2 is shown in Fig. 5, and so on for others.
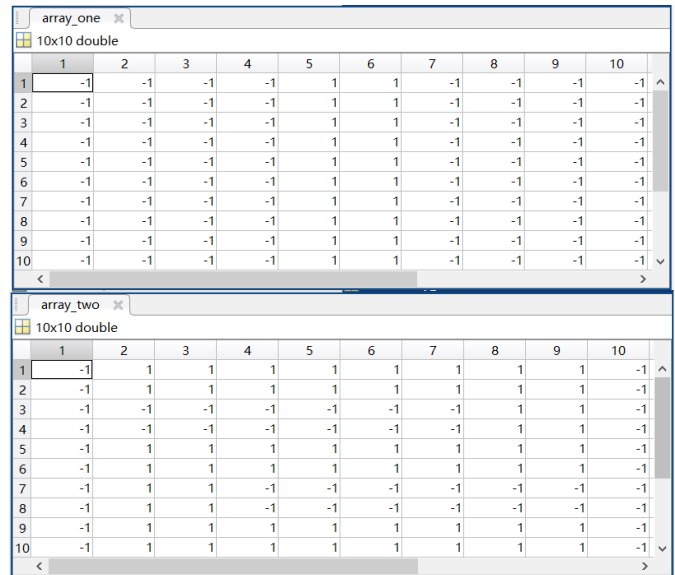


Fig. 5. Digital dot matrix of 1-2.

### B. Noise Experimental Data Description

A noisy digital lattice is that some positions of lattice have changed. We employ random noise for this purpose. A random function is used to determine the position that needs to be modified, and then the digital lattice is noised. That is, according to the position determined by the random function, the original 1 becomes -1 and -1 becomes 1.

### C. Digit Recognition of the Original DHNN

Suppose that DHNN memorizes a steady state of 10 numbers from 0 to 9. The steady state of standard number is used as training sample, and the digital lattice with adding noise is used as testing sample. The following two experiments are designed. In the first case, only 2 numbers are input, and the output of DHNN is observed as the noise intensity increases. In the second case, when the input increases to 4 numbers, how will the output change with the noise increases.

From the structure of DHNN, it is known that its stable state is the minimum of energy function during the training process. In the process of number recognition, the curve of energy function changing with the iteration is shown in Fig. 6.
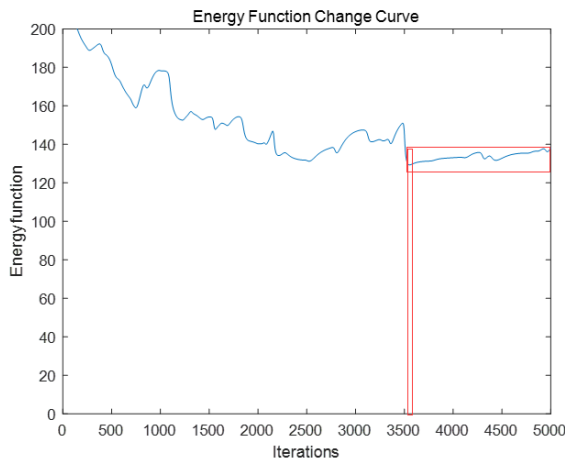
Fig. 6.   Energy function change curve (DHNN).

Fig. 6 shows that the energy of DHNN decreases continuously with the iterative process. Until the iteration reaches 3500 times, the energy of DHNN changes very little (the red circled part in the figure). It indicates that the network tends to be in a stable state at this time.

In the first case, the lattices of numbers 1 and 2 are fed into DHNN as training samples. In the absence of noise (the noise is so small that it can be ignored), the network can accurately identify standard digital lattices. Subsequently, 10% (that is, 10% of the positions in 10*10 matrix have changed) and 30% of the noise intensity are added to the test sample and sent to DHNN again. The recognition result is shown in Fig. 7.
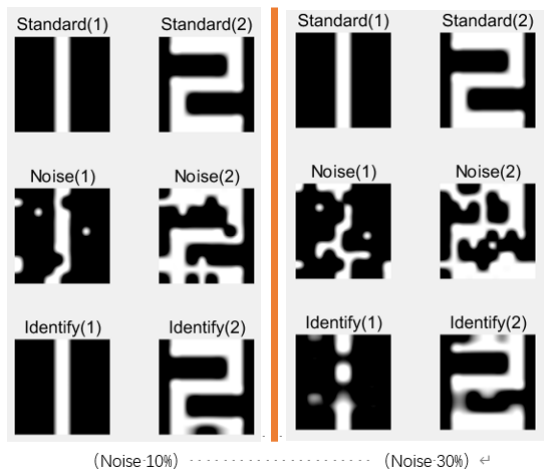


Fig. 7.   Recognition effect with 2 numbers (DHNN).

Fig. 7 shows that the recognition clarity of DHNN is reduced after adding 10% noise, but it can be accurately identified, and the recognition effect of network is good. When the noise intensity increases to 30%, the recognition clarity of DHNN is further reduced compared to the previous one, but the numbers can still be distinguished, and the recognition effect of network is not very good. It shows that DHNN has the function of associative memory, which can correctly identify the digital lattice with certain noise.

In the second case, the number of input samples has been increased from 2 to 4. In the absence of noise, the recognition effect of DHNN is equivalent to having only 2 inputs. The accuracy reaches 100%. Subsequently, the digital lattice as input is replaced with a noise matrix with 10% and 30%. The recognition effect of DHNN is shown in Fig. 8 and Fig. 9.
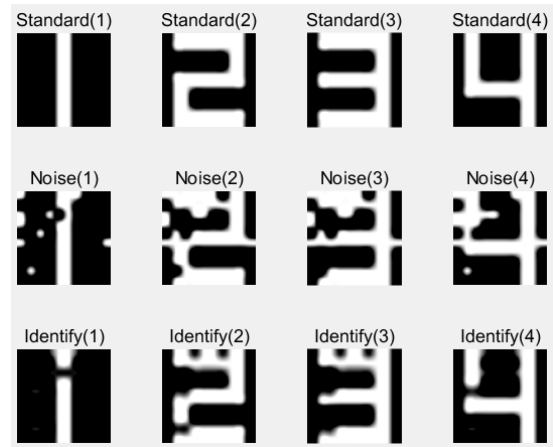


Fig. 8.   Recognition effect adding noise 10% with 4 numbers (DHNN).
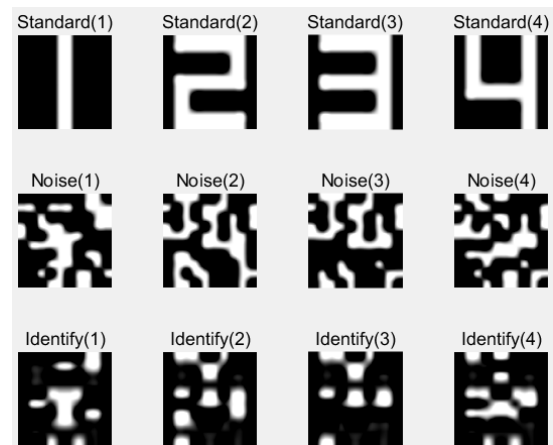


Fig. 9.   Recognition effect adding noise 30% with 4 numbers (DHNN).

The output results show that when the input increase to 4 digits, the recognition performance of DHNN is significantly worse than 2 digits. When the noise intensity is 10%, Fig. 8 can clearly recognize the output of network, but compared to the Fig. 7, the recognition clarity of DHNN has dropped. When the noise intensity continues to increase, the associative memory ability of network further deteriorates, the error rate increases, and the recognition ability plummets. When the noise intensity reaches 30%, Fig. 9 shows that DHNN has difficulty in identifying 4 digits. The output of network is completely unrecognizable, and the recognition effect is extremely poor. In the case of 2 digits, although the recognition clarity is not good, the result can be roughly identified. Continue the experiment and found that when the input is 10 numbers from 0 to 9, even if the noise intensity is 10%, DHNN also fails.

From these two experiments, it can be seen that the associative memory ability of DHNN decreases with the increase of input scale. At the same time, the recognition

performance of network is inversely proportional to the noise intensity. The reason for this result is that there are many pseudo-stable points in DHNN, and it is difficult for the network to achieve a real steady state. Therefore, in order to maintain good performance of DHNN under high noise intensity, it is necessary to optimize the network structure.

*D. Digit Recognition of the Improved DHNN*

In order to jump out the pseudo-stable point, we optimize the structure of DHNN in two stages to make the network have better anti-interference. In the first stage, the global search ability of PSO is used to optimize the weight of DHNN to obtain weights with higher accuracy. In the second stage, SVD is used to redesign the weight matrix of DHNN to realize the sparseness of weights. Finally, the I-SVD-DHNN model is obtained.

Firstly, the weight of DHNN is optimized by PSO. In the experiment, the parameters of PSO are set as follows.

Inertia weight ($W$): it enables particles to maintain the inertia of motion and continue to expand the exploration space. In this experiment, $W$=0.25.

Acceleration coefficients $C_1$ and $C_2$: it represents the weight of acceleration term each particle towards the pole position. In this experiment, $C_1$=$C_2$=0.01.

Number of Particles: In general, 20-40 can be selected. In this experiment, 20 particles are selected.

Secondly, the weight of DHNN is sparsed by SVD. For the weights optimized by PSO in the previous stage, SVD is used to extract their important features to form a new weight matrix. According to the contribution rate ($C$) of weights to the network output, it is decided whether to retain the corresponding weight. If $C>h$, keep the weight, otherwise delete it. In this way, a set of simple and sparse network weights can be obtained, which can ensure the network converging to a steady state. In this experiment, $h$=0.15.

In order to test the performance changes before and after the improvement, similar to Part C, the I-SVD-DHNN is first trained by using the standard digital lattice, and then different input and noise intensities are sent as test samples to observe the recognition effect of model. The contrast experiment is designed for two situations. Firstly, there are only 2 numbers. Secondly, the input is increased to 4 numbers.

Before starting the classification experiment, let's compare the stability of network. During the training process, the energy value of I-SVD-DHNN is also shrinking to the minimum. Its trend is shown in Fig. 10.

Fig. 10 shows that I-SVD-DHNN converges rapidly in the initial stage, and the energy value drops rapidly. After a period of small fluctuations, it tends to the minimum. It will reach a stable state after about 900 iterations (the red circled part in the figure). Compared with Fig. 6, the improved model I-SVD-DHNN has a rapid improvement in performance.
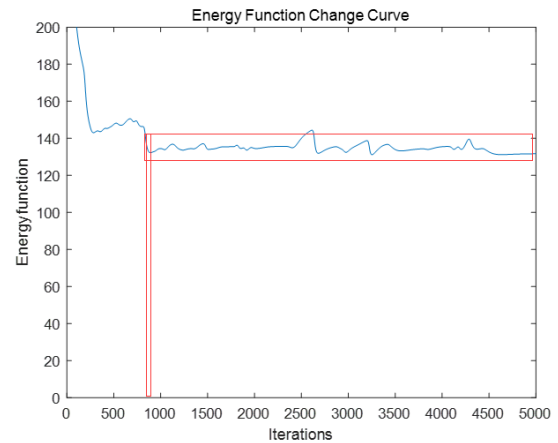


Fig. 10. Energy function change curve (I-SVD-DHNN).

*1)* The standard numbers 1 and 2 are sent into the I-SVD-DHNN. Subsequently, 10% and 30% of noise intensity are added for testing. The output of network is shown in Fig. 11.
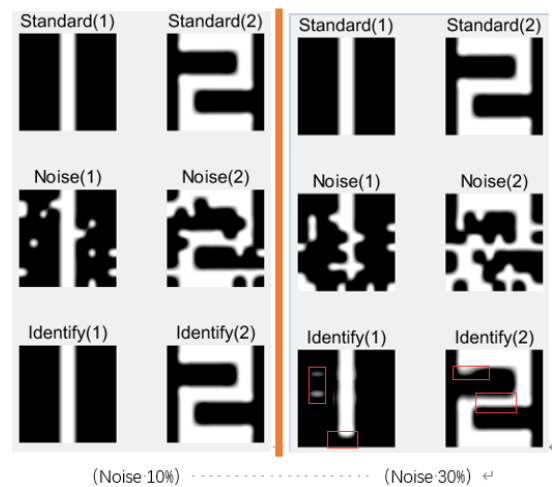


Fig. 11. Recognition effect with 2 numbers (I-SVD-DHNN).

Fig. 11 shows that after adding 10% of the noise, the network can accurately identify, and the recognition effect is close to the standard digital lattice, and the recognition rate reaches 100%. When the noise intensity is increased to 30%, the recognition performance of network decreases slightly. There are some borders with burrs (the red circled part in the figure), but the recognition effect is second only to the standard lattice. That is, the burrs have no effect on the output results. Compared with Fig. 7, the recognition performance of I-SVD-DHNN improves with the increase of noise intensity.

*2)* In I-SVD-DHNN, the number of training samples is increased to 4 digits, and the test sample are also added with 10% and 30% of noise intensity. The output of network is shown in Fig. 12 and 13.
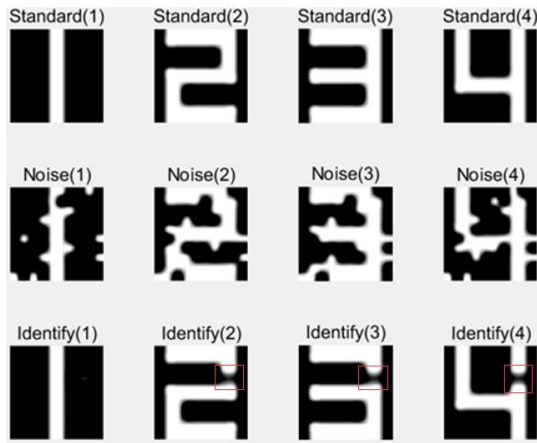
Fig. 12. Recognition effect adding noise 10% with 4 numbers (I-SVD-DHNN).
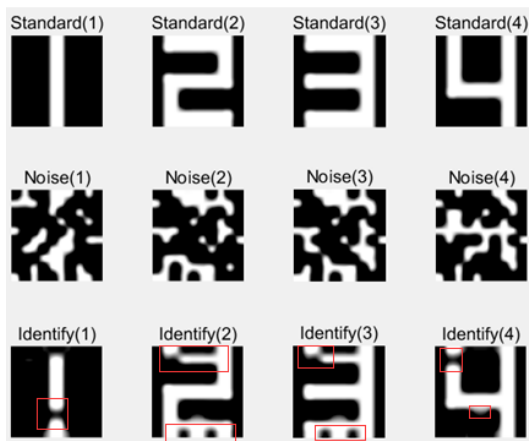


Fig. 13. Recognition effect adding noise 30% with 4 numbers (I-SVD-DHNN).

Fig. 12 and Fig. 13 show that the recognition performance of I-SVD-DHNN is significantly better than DHNN, when the input is 4 digits. When the noise intensity is 10%, the effect of Fig. 12 is slightly inferior to that of Fig. 11. Although it can be accurately identified, the number 2, 3, and 4 have a small missing (the red circled part in the figure), which does not achieve the effect of standard digital lattice. It shows that the recognition rate of I-SVD-DHNN is indeed related to the input scale of network. On the other hand, the effect of Fig. 12 is much better than that of Fig. 8 for the same input and noise intensity. When the noise intensity increases to 30%, Fig. 9 has completely failed while Fig. 13 still identified, but the accuracy of Fig. 13 has decreased. Compared with Fig. 12, some missing segments are added to the Fig. 13(the red circled part in the figure), which reduces the clarity of result, but it does not affect the output.

In order to further verify the effectiveness and practicability of I-SVD-DHNN, different thresholds are set to observe the difference of network recognition effects. Experiments are performed at 0.05 intervals. As $t$ increases, more and more weights are removed. The recognition performance of network starts to decline. The deletion rate of weight and accuracy rate of result corresponding to different $t$ are shown in Table I.

TABLE I.        Accuracy vs Threshold

| threshold | deletion rate of weight(%) | accuracy rate of result (10% noise) | accuracy rate of result (30% noise) |
|---|---|---|---|
| 0 | 0 | 100 | 100 |
| 0.05 | 5 | 100 | 100 |
| 0.1 | 12 | 100 | 90 |
| 0.15 | 22 | 100 | 80 |
| 0.2 | 56 | 85 | 60 |
| 0.25 | 70 | 50 | 0 |
| 0.3 | 70 | 0 | 0 |

Table I shows that the recognition effect is good when $t=0$, which is equivalent to retaining all the optimized weights by PSO. When $0<=t<=0.15$, some of the network weights are removed, but it does not affect the recognition effect. When the noise intensity is added to 10%, the recognition rate reaches 100%. When the noise is increased to 30%, the recognition rate of 80% can also be achieved, indicating that some insignificant weights are deleted and the purpose of sparing network structure is achieved. When $t=0.2$, 56% of the weights are removed, but numbers with a noise intensity of 10% can still be identified. Relatively speaking, the recognition rate with a noise intensity of 30% drops further to 60%, and it is impossible to recognize all the test samples. When $t=0.25$, 70% of the weights are deleted, resulting in a large loss of information stored in the weights, only about half of the numbers can be recognized. If you continue to increase $t$, it is found that the deletion rate of weights remains the same. It means that the remaining weights cannot be deleted further. The network is in failure and the sample cannot be identified. The experimental results show that it is the best state to select 0.15 for the $t$, which can ensure the accuracy of digit recognition while achieving the sparse network structure.

To sum up, the recognition performance of I-SVD-DHNN is enhanced with the increase of input scale and noise intensity. The overall identification ability of network is improved and the anti-interference ability is strengthened. The conclusion is just consistent with the results described in Fig. 6 and 10. Both of them verify that the performance of I-SVD-DHNN is better than DHNN.

## IV.    CONCLUSION

As an important part of character recognition, digital recognition is widely used in transportation, post, business and other fields. Based on the original DHNN, this paper proposes an improved I-SVD-DHNN network model. The new model not only continues the associative memory ability of DHNN, but also improves its versatility and anti-interference. Firstly, it optimizes the weights of network by using the global search capability of PSO. The particle information with the minimum fitness is found as the optimized weight matrix through multiple iterations to avoid the network falling into local optimization. Secondly, it readjusts the weight matrix with the help of SVD and stores the information of target into it. Whether to retain or not is determined according to the contribution of each weight to output. By removing some insignificant weights, the purpose of sparse weight matrix is

achieved. Finally, the validity and applicability of new model are verified by means of digital recognition. Therefore, the following conclusions are drawn.

*1)* Optimize the weight matrix by PSO. It makes full use of the global optimization ability of PSO, so that the model tends to be stable in a short time, converges quickly, and obtains a weight matrix with higher accuracy to ensure the effectiveness of I-SVD-DHNN.

*2)* Sparse the weight matrix by SVD. It can effectively optimize the weight and greatly reduce the complexity of network structure, so that the optimized I-SVD-DHNN with sparse matrix has better recognition performance and it is more suitable for large-scale recognition scenarios.

*3)* The new method I-SVD-DHNN proposed in this paper has proved its feasibility and accuracy through experiments based on 0-9 digital samples. In the future, we will consider adding character samples, or even a mixture of the two, to further test the performance of the model.

## References

[1] Jena K K , Bhoi S K , Nayak S R ,et al. Deep Convolutional Network Based Machine Intelligence Model for Satellite Cloud Image Classification[J]. Big Data Mining and Analytics, 2023, 6(1):12.

[2] Belyaev M A , Velichko A A . Classification of handwritten digits using the Hopfield network[J]. IOP Conference Series Materials Science and Engineering, 2020, 862:052048.

[3] Zhou X , Huang J , Lu F , et al. HNN-Based Generalized Predictive Control for Turbofan Engine Direct Performance Optimization[J]. Aerospace Science and Technology, 2021, 112(3):106602.

[4] Lu J , Wu Z , Zhang X , et al. Quantitatively Evaluating the Effect of Read Noise in Memristive Hopfield Network on Solving Traveling Salesman Problem[J]. IEEE Electron Device Letters, 2020, 41(11):1688-1691.

[5] Zhang L, Yang Y. Stability Analysis of Fractional Order Hopfield Neural Networks with Optimal Discontinuous Control[J]. Neural Processing Letters, 2019,50(1):581-593.

[6] Feng L, Cao J, Liu L. Stability Analysis in a Class of Markov Switched Stochastic Hopfield Neural Networks[J]. Neural Processing Letters, 2019,50(1):413-430.

[7] Wang J, Liu X, Bai J, et al. A New Stability Condition for Uncertain Fuzzy Hopfield Neural Networks with Time-varying Delays[J]. International Journal of Control, Automation and Systems, 2019,17(5):1322-1329.

[8] Shi Z , Yu T , Zhao Q , et al. Comparison of algorithms for an electronic nose in identifying liquors. Journal of Bionic Engineering, 2008, 5(3):253-257.

[9] Zhang Y , Li T , Na G , et al. Optimized Extreme Learning Machine for Power System Transient Stability Prediction Using Synchrophasors [J]. Mathematical Problems in Engineering, 2018, 23:1-8.

[10] Keddous FE, Nakib A. Optimal CNN–Hopfield Network for Pattern Recognition Based on a Genetic Algorithm[J]. Algorithms. 2022; 15(11):1-18.

[11] Zhao S , Chen B , Wang H , et al. A Feed-Forward Neural Network for Increasing the Hopfield-Network Storage Capacity[J]. International Journal of Neural Systems, 2022, 32(6): 2250027-2250043.

[12] Sahoo R C , Pradhan S K . Pattern Storage and Recalling Analysis of Hopfield Network for Handwritten Odia Characters Using HOG[C]// ICMLCI. 2019.

[13] Brot Hilla, Muchnik Lev, Goldenberg Jacob, et al. Feedback between node and network dynamics can produce real-world network properties[J]. Physica A, 2012,391(24):6645-6654.

[14] Luo Y. Design and Improvement of Hopfield network for TSP[C]// International Conference on Artificial Intelligence. ACM, 2019.

[15] Shi H , Rao Y. et al. A New Approach for Solving Medium Scale TSP Based on Hopfield Neural Network[J]. China Transportation Review, 2018,40(10):77-82.

[16] Chen Y , Xue Y , Zhang X .A direct analysis method to state bounding for high-order quaternion Hopfield neural networks with mixed delays and bounded disturbances[J]. Mathematical Methods in the Applied Sciences, 2023,46(8):8646-8662.

[17] Huang Y , Watanabe T , Bando M , et al. PSO algorithm parameter settings and optimal multi-rotor layout design[J]. International journal of sustainable aviation, 2022,8(2):116-135.

[18] Liu X , Wu Y , Gao P , et al. Color image watermarking based on singular value decomposition and generalized regression neural network[J]. Multimedia Tools and Applications, 2022, 81(22):32073-32091.

[19] Song F , Li L , Liu Y ,et al. Singular value decomposition based learning identification for linear time-varying systems: From recursion to iteration[J]. International Journal of Robust and Nonlinear Control, 2023, 33(12):6986-7003

# The GSO-Deep Learning-based Financial Risk Management System for Rural Economic Development Organization

Weiliang Chen

Shanghai Open University Jingan Branch; Shanghai Jingan District College, Shanghai, China

*Abstract*—**Financial risk management has always been a key concern for major enterprises. At the same time, with the continuous attention to impoverished rural areas worldwide, financial risk management tools have become an important component of rural economic development organizations to avoid financial risks. With the rapid development of artificial intelligence technologies such as neural networks and deep learning, and due to their strong learning ability, high adaptability, and good portability, some financial risk management tools are gradually adopting technologies such as neural networks and machine learning. However, existing financial risk management tools based on neural networks are mostly developed for large enterprises such as banks or power grid companies, and cannot guarantee their full applicability to rural economic development organizations. Therefore, this study focuses on the financial risk management system used for rural economic development organizations. In order to improve the accuracy of deep learning algorithms in predicting financial risks, this paper designs an improved Glowworm Swarm Optimization (IGSO) algorithm to optimize Deep Neural Networks (DNN). Finally, the effectiveness of the financial risk management tool based on IGSO-DNN proposed in this article was fully validated using data from 45 rural economic development organizations as a test set.**

*Keywords*—*Deep learning; Glowworm Swarm Optimization (GSO) algorithm; Deep Neural Networks (DNN); financial risk prediction; rural economic development organization*

## I. INTRODUCTION

Financial risk management aims to reduce the probability of adverse risks and mitigate their impact on the enterprise, in order to maintain the financial health and sustainable development of the enterprise. It is an important means to reduce the adverse effects of the enterprise's financial condition and operating performance, and protect the financial interests of the enterprise [1]. Financial risk prediction provides the main data and information for financial risk management, thereby providing the decision-making basis and foundation for financial risk management for enterprises. Specifically, financial risk prediction can be based on historical data, market trends, industry analysis, macroeconomic and other indicators to predict potential financial risk events and their potential impacts [2]. Financial risk prediction helps enterprises identify and evaluate risks in advance, develop corresponding risk management strategies and measures, and reduce the adverse impact of financial risks on the enterprise. It can be said that

financial risk prediction is an important component of financial risk management [3].

The financial ratio analysis method evaluates the financial condition of a company by calculating financial indicators such as debt ratio and current ratio. The trend analysis method predicts the future financial condition of a company by observing historical trends in data, and the financial model risk prediction method based on statistical and empirical methods are three traditional financial risk prediction methods, which have high universality and advantages. However, the above three methods also have drawbacks such as low prediction accuracy, susceptibility to limitations in predictions from different industries, and high dependence on data reliability. For example, early risk management systems based on option pricing models had high universality, but their risk prediction performance was not very ideal [1]. Therefore, in early research related to financial risk management, the purpose of a large amount of research was to develop financial risk management tools that can effectively communicate with organizations in the market, rather than improving the accuracy of financial risk prediction models and the reliability of results.

With the advancement of relevant technologies in the field of artificial intelligence, financial risk prediction methods based on cutting-edge technologies such as neural networks, snake venom learning, and machine learning in the field of artificial intelligence are receiving widespread attention from relevant researchers. Learning based financial risk prediction methods can better handle large amounts of data, nonlinear relationships, and complex risk factors, and are expected to bring higher accuracy and reliability to financial risk prediction [3]. Indicative examples include risk management for large financial enterprise investment portfolios based on deep learning [4], enterprise financial risk prediction methods based on genetic algorithms and Support Vector Machines (SVM) [5], and power company financial risk prediction methods based on machine learning [6].

When using machine learning and other methods for financial risk prediction, the first step is to prepare a financial dataset for prediction, including financial statements, economic indicators, etc. At the same time, it is necessary to preprocess the data, including steps such as data cleaning, feature selection, and standardization. Furthermore, it is necessary to select appropriate features from financial data based on the objectives of financial forecasting. Common features include profit, sales, cash flow, etc. Finally, the prediction model is

trained and evaluated. In addition, some studies will also further optimize the model, such as selecting genetic algorithms for SVM optimization in study [5].

However, in recent years, rural counties in the United States have replaced large cities as the most difficult areas, and this situation is similar in most parts of the world [7]. With the proposal of the United Nations Sustainable Development Goals, the global attention to economically disadvantaged rural areas is also constantly increasing. This has led to increased funding for difficult rural areas by rural economic development organizations, including the World Bank's rural development department, the Agricultural Development Bank (ADB), the International Fund for Agricultural Development (IFAD), La Via Campesina, and the Rural Development Foundation [7]. These agricultural economic development organizations usually collaborate with local-residents to provide assistance to the impoverished population in the form of rural cooperatives [8].

In order to ensure the sustainable development of rural economic development organizations, rural economic development organizations need to use financial risk management tools to protect their agricultural assets and improve the financial health of rural economic development organizations, in order to attract investment for rural economic development organizations and ultimately achieve sustainable development of rural economic development organizations, maintain agricultural production and stability of rural economy [9]. Therefore, it is necessary to develop corresponding financial risk prediction tools for rural economic development organizations. However, as previously mentioned, existing risk prediction systems based on artificial intelligence methods are mostly used for power, finance, and investment enterprises, rather than agricultural enterprises with agricultural economic development organizations as the main body.

Therefore, this study focuses on the study of a financial risk prediction system for rural economic development organizations, aiming to help them protect organizational assets, improve financial health, increase investment attractiveness, and promote sustainable development of the organization. The main contributions of this article are summarized as follows: Firstly, based on the possible risk sources of rural economic development organizations and the Analytic Hierarchy Process, a deterministic financial risk system was established, aiming to predict financial risks based on the current operating conditions of the company. Furthermore, a novel deep learning prediction algorithm was designed to optimize the Deep Neural Network (DNN) using the improved Glowworm Swarm Optimization (GSO) algorithm, thereby designing the optimal number of DNN layers and parameters, and improving prediction accuracy. Finally, this article used 110 test sets and 45 test sets, and compared the IGSO-DNN algorithm designed in this article with the other two algorithms to verify the effectiveness of the algorithm designed in this article.

The rest of this article is arranged as follows, and the work related to this study is reviewed in the Section II. In Section III, A financial risk prediction model has been established. The Section IV introduces the GSO algorithm. In Section V, the improved GSO algorithm was designed and a model of DNN based on the improved GSO algorithm was developed. The Section VI presents and discusses the simulation experimental results. Finally, the full text is summarized in Section VII.

## II. RELATED WORKS

This article aims to establish a financial risk prediction tool for rural economic development organizations and use the improved GSO-based DNN algorithm (IGSO-DNN). Therefore, this article reviews the relevant work from three perspectives: financial risk prediction, swarm intelligence algorithms, and machine learning algorithms.

### A. Financial Risk Prediction

As previously mentioned, traditional financial risk prediction models have drawbacks such as low accuracy and high requirements for data accuracy [1]. Therefore, this article focuses on financial risk prediction methods based on logistic regression, decision trees, random forests, SVM, and neural networks. In order to enrich the financial risk prediction system based on SVM, works [5], [10]-[11] all used Support Vector Machines (SVM) to predict the financial risk of enterprises. Unlike the simple improvement of SVM algorithm in [10]-[11], work [5] optimizes SVM algorithm based on genetic algorithm (GA), aiming to improve the prediction accuracy of SVM algorithm. The above three studies are based on the actual operational situation of the company, and predict the financial risk of the company based on information such as the intensity of capital investment, capital loss rate, and product net profit. However, Tsai et al. used information from the company's financial reports to predict the company's financial risks [12].

Unlike the above efforts to improve the accuracy of financial forecasts, the work [13] aims to reduce the cost of misclassification. Chen et al. used a Markov chain based Monte Carlo method to predict the financial risks of enterprises before and after economic crises. This study helps companies avoid financial risks caused by economic crises. Reference [14] studies the impact of intelligence services on sustainable financial risk management of enterprises from the perspective of green finance. Yang et al. aim to improve the financial management capabilities of enterprises and provide sustainable financial management plans for them [15]. Specifically, Yang et al. used deep learning methods to predict the degree of financial risk in enterprises and developed a financial risk prediction framework based on DNN [16]. This study explores the application of DNN in financial risk prediction. Reference [17] conducted research on enterprise financial risk prediction models based on BP neural networks, further proving the superiority of AI based financial risk prediction models compared to traditional methods.

Similar to study [14], research in [18] also studied the financial risk prediction of enterprises based on the Markov chain Monte Carlo method, which mainly focuses on the financial market and has certain significance for the development of the financial market. The study in [19] is also based on deep learning to evaluate credit risk, which is also a model for financial risk assessment. The research in [20] studied a credit risk prediction model based on graph neural

networks, which evaluates and predicts credit risk based on high-dimensional data and different economic cycles. The above two studies on credit risk prediction have certain reference significance for financial risk prediction. Peng et al. conducted research on several mainstream financial risk prediction methods to evaluate the effectiveness of nine financial prediction algorithms [21].

### B. Swarm Intelligence Algorithm

Similar to study [5], this article uses swarm intelligence algorithms to optimize DNN, aiming to improve its performance. At present, with the increasing frequency of large-scale complex problems, swarm intelligence algorithms are also widely studied [22].

The GSO algorithm, as a relatively novel swarm intelligence algorithm, has been widely used in optimization problems since its inception. Reference [22] provides a detailed introduction to the basic principle, process, and parameter settings of the GSO algorithm, and verifies its performance through experiments on multimodal optimization problems. The research in [23] elaborates on the principle and application of GSO algorithm, and provides new ideas for improving and expanding GSO algorithm. The study in [24] mixed the GSO algorithm with another swarm intelligence algorithm and conducted experiments on complex global optimization problems. The experimental results show that the hybrid GSO algorithm has higher accuracy and convergence speed in global optimization compared to traditional GSO swarm algorithms. The study in [25] provides a detailed introduction to the application of GSO algorithm in the field of intelligent manufacturing, and prospects its applications in power system scheduling, network routing, resource allocation, image processing, and other fields.

Particle Swarm Optimization (PSO) algorithm, as a heuristic algorithm, is widely used in fields such as robot path planning, image recognition, vehicle scheduling, and flight planning [26]. The research in [27] introduces improvement strategies for the PSO algorithm, including introducing inertia weights, limiting maximum speed, and other strategies to improve the algorithm's search ability and optimization performance. It also analyzes the convergence and stability of the PSO algorithm. The study in [28] introduces the idea of differential evolution based on PSO algorithm, enabling it to better handle high-dimensional optimization problems. The research in [29] summarizes the application of PSO algorithm in different fields, explores the three-dimensional performance and applicability of the algorithm in solving large-scale complex problems through multiple experimental cases, and proposes corresponding improvement strategies. The study in [30] studied the application of PSO algorithm in the field of data clustering and analyzed their performance and effectiveness in clustering problems. The research in [31] focuses on the application of PSO algorithm in supply chain optimization problems. Introduced the construction of a supply chain optimization model and algorithm design scheme based on particle swarm optimization algorithm, and discussed the advantages of PSO algorithm in supply chain optimization.

Similarly, the Whale Optimization Algorithm (WOA) has also received widespread attention from relevant researchers in [32]. The study in [33] studied the application of improved MVO algorithm in indoor positioning systems, aiming to improve the positioning accuracy of WOA algorithm in visible light systems. Gharehchopogh et al. systematically investigated the latest research progress in WOA. The study introduces the advantages and limitations of the WOA algorithm, and evaluates its application effectiveness in different fields through a series of experiments [34]. The research in [35] proposed an improved WOA based on chaotic mutation and applied it to the optimization process of large-scale complex problems. The performance of the algorithm was demonstrated through various standard test functions and comparative experiments. Based on the review of the above content, we improve the GSO algorithm and compare it with PSO and WOA algorithms.

### C. Deep Learning

The study in [36] provides a comprehensive introduction to the development, algorithms, and applications of deep learning. The article discusses the structure and training methods of deep learning models, and proposes some future research directions for deep learning. This study covers the basic principles of deep learning, neural network architecture, parameter optimization methods, and reviews the applications of deep learning in speech recognition, image classification, natural language processing, and other fields. The research in [37] designed a novel deep learning algorithm to improve the accuracy and fairness of deep learning in the decision-making process, thereby optimizing multi-objective optimization problems. The study in [38] focuses on optimizing the dynamic performance of aircraft airfoils and designs a deep learning algorithm for multi-objective optimization, aiming to reduce the gap between the solution results and the Pareto front. The study in [39] designed a recursive neural network to predict the financial risks of enterprises.

### III. FINANCIAL RISK MODEL

By summarizing the various indicators related to financial risk prediction in literature [1]-[7]. Based on the Analytic Hierarchy Process, four indicators directly related to financial risk are summarized, namely Funding risk (A1), Investment risk (A2), Operational risk (A3), and Liquidity risk (A4). Furthermore, the four types of risks are divided into 11 indicators that directly constitute the four types of risks, as follows:

- Funding scale (B1)

- Financing time (B2)

- Funding cost (B3)

- Risk of capital investment (B4)

- Profitability (B5)

- Operating capacity (B6)

- Procurement Risk (B7)

- Inventory Shortage Risk (Production Risk) (B8)

- Inventory realization risk (B9)

- Long term fund repayment risk (B10)

- Short term fund repayment risk (B11)

Table I shows the various indicators generated at three levels based on the Analytic Hierarchy Process.

Furthermore, we will use expert back-to-back scoring to determine the importance of each indicator in the C-layer on financial risk impact. In addition, the risk level is divided into six levels, represented by the numbers 1-6, and divide the intervals into [0, 0.2163], [0.2163, 0.3694], [0.3694, 0.4837, 0.6405], [0.6405, 0.8379), [0.8379, 1] representing safety, low risk, low medium risk, medium high risk, and high risk. Based on the collected data on the rationality of fundraising scale, funding availability time, and fund usage time, along with the other 11 indicators listed in Table I, we will Normalize the relevant indicators of 155 companies, The details are shown in Table II.

TABLE I.    STRATIFICATION OF FINANCIAL RISK SOURCES BASED ON ANALYTIC HIERARCHY PROCESS

| Layer A | Layer B | Layer C |
|---|---|---|
| A1-Financing risk | B1-Funding scale | C1-Rationality of fundraising scale |
| | B2-Financing time | C2-Funding availability time |
| | | C3-Fund usage time |
| | B3-Funding cost | C4-Comprehensive financing cost |
| A2-Investment Risk | B4-Risk of capital investment | C5-Capital investment intensity |
| | | C6- Capital loss rate |
| | B5-Profitability | C7- Product net profit |
| | B6-Operating capacity | C8- Asset turnover rate |
| | | C9- Product turnover rate |
| A3-Business risk | B7-Procurement Risk | C10-Supplier stability in the raw material market |
| | B8-Inventory shortage risk (Production risk) | C11-Insufficient inventory |
| | B9-Inventory realization risk | C12-Market demand stability |
| A4-Liquidity risk | B10-Long term fund repayment risk | C13- Asset liability ratio |
| | B11-Short term fund repayment risk | C14-Cash ratio |

TABLE II.    NORMALIZATION RESULTS OF EACH INDICATOR

| | C1 | C2 | C3 | C4 | C5 | … | C13 | C14 |
|---|---|---|---|---|---|---|---|---|
| E1 | 0.8147 | 0.2784 | 0.9571 | 0.7922 | 0.6787 | … | 0.2769 | 0.9502 |
| E2 | 0.9057 | 0.5468 | 0.4853 | 0.9594 | 0.7577 | … | 0.0461 | 0.0344 |
| E3 | 0.1269 | 0.9575 | 0.8002 | 0.6557 | 0.7431 | … | 0.0971 | 0.4387 |
| E4 | 0.7655 | 0.7093 | 0.1189 | 0.7512 | 0.5472 | … | 0.1965 | 0.5852 |
| E5 | 0.7951 | 0.7546 | 0.4983 | 0.2550 | 0.1386 | … | 0.2510 | 0.5497 |
| … | … | … | … | … | … | … | … | … |
| E154 | 0.9171 | 0.0758 | 0.5688 | 0.3112 | 0.6892 | … | 0.1066 | 0.0844 |
| E155 | 0.2858 | 0.0539 | 0.4693 | 0.5285 | 0.7481 | … | 0.9618 | 0.3997 |

## IV.    GLOWWORM SWARM OPTIMIZATION

The GSO algorithm is an algorithm generated by fireflies moving towards a light source. During the optimization process, it randomly generates a group of firefly populations in the search space and assigns an initial brightness value to each firefly individual. Furthermore, each individual firefly updates its position through a movement strategy based on its current position and the brightness information of surrounding fireflies. The goal of moving is to move towards higher brightness in order to find a better solution. Fireflies communicate information between individuals by emitting and receiving light signals. A firefly will emit a light signal, and its brightness value will decrease with increasing distance. Other fireflies determine whether there is a brighter solution around them based on the received light signal and selectively move towards the direction of the light source.

This algorithm optimizes the search process by updating the fluorescence of individual fireflies, calculating their mobility probability, updating their positions, and updating their neighborhood ranges. The specific steps are as follows:

*1) Update the fluorescence:* Each firefly's luminescence value is equal to the luminescence value from the previous moment plus a certain extraction proportion of the current firefly's fitness value. This is then subtracted by a certain proportion of luminescence value that evaporates over time. The mathematical description is as follows:

$$\beta_x(\delta+1) = (1-\rho) \times \beta_x(\delta) + \chi \times F\left[\beta_x(\delta)\right] \qquad (1)$$

where, $\beta_x(\delta+1)$ represents the concentration of fluorescein in individual $x$ of the firefly during $\delta+1$ iterations. $\rho$ is the fluorescence emission coefficient, and $\chi$ is the fitness

extraction ratio. $F\left[\beta_x(\delta+1)\right]$ is the fitness function value of firefly $x$ during $\delta$ iterations.

*2) Calculate the mobility probability:* During the specific movement of each firefly, it needs to determine its direction based on the luminescence concentration of all neighboring fireflies within its decision radius. $V_{xn}(\delta)$ represents the probability at time $\delta$ (iteration) that the firefly moves towards the neighboring firefly. The calculation formula is as follows:

$$V_{xn}(\delta) = \frac{\beta_n(\delta) - \beta_x(\delta)}{\sum\left(\beta_m(\delta) - \beta_x(\delta)\right)} \quad (2)$$

where, $V_{xn}(\delta)$ represents the probability of the $x$-th firefly moving towards the $n$-th neighbor firefly individual during the $\delta$-th iteration process.

*3) Update the positions:* Selecting the maximum movement probability and updating the position: Firefly $D_x(\delta)$ moves a certain distance towards the firefly with the maximum luminescence within its decision radius. The movement formula at time $\delta+1$ is as follows:

$$D_x(\delta+1) = D_x(\delta) + \theta\frac{D_n(\delta) - D_x(\delta)}{\left\|D_n(\delta) - D_x(\delta)\right\|} \quad (3)$$

*4) Update the neighborhood ranges:* Each firefly adopts an adaptive dynamic decision radius, changing its decision radius based on the density of neighboring fireflies during each iteration. When the neighbor density is low, it increases the decision radius to search for more neighbors. Conversely, when the neighbor density is high, it decreases the decision radius.

## V. PROBLEM SOLVING APPROACH

Deep neural networks (DNN) are powerful machine learning techniques rooted in the concept of artificial neural networks. These algorithms facilitate the learning and prediction of vast datasets through the combination of multi-layered neurons. Fig. 1. shows the architecture of DNN [40]-[41]. The primary advantage of DNN lies in their adeptness at feature learning, enabling them to automatically extract high-level abstract features from raw data, thereby enhancing the predictive performance of models. While DNN have demonstrated impressive results across various domains, their performance in tasks, such as risk level prediction, continues to be challenged by the optimization of model parameters. To tackle this issue, this study introduces a method based on the GSO algorithm for optimizing parameters within deep learning networks, ultimately enhancing prediction accuracy and robustness.

Within the GSO algorithm, each individual relies on a nearby superior individual to provide guidance during the search process. If there is no such superior individual within the perceptual range, the individual becomes unable to continue the search, rendering the algorithm heavily reliant on these superior individuals. This dependency can potentially

slow down convergence speed. Moreover, as an individual approaches the optimal solution, it might oscillate around that solution due to its step size exceeding the remaining distance. This oscillation can also impact the algorithm's performance.
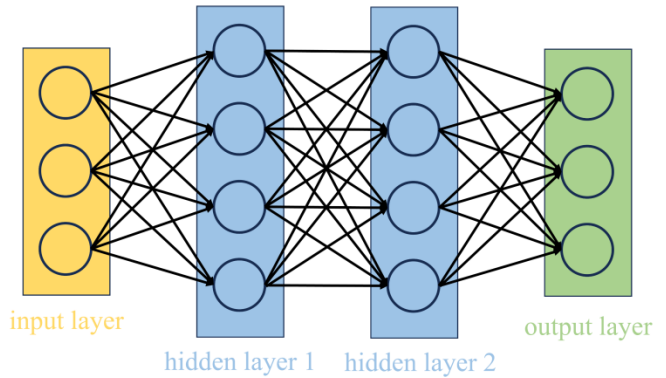


Fig. 1. DNN architecture.

To address these issues, the incorporation of an elite reservation strategy is proposed into the GSO algorithm. This addition aims to enhance the algorithm's convergence speed and accuracy. In the GSO algorithm, the elite strategy involves maintaining the positions of both optimal and suboptimal individuals unchanged while updating the positions of individuals in the population. By combining this enhanced GSO algorithm with deep learning techniques, this study aims to develop an efficient and accurate method for predicting risk levels. Specifically, following these steps:

*1)* Initialization: Start by randomly generating an initial set of parameters (weights and biases) to form the foundation of the neural network. Simultaneously, configure the parameters of the GSO algorithm, including population size, the number of iterations, step size, and neighborhood threshold.

*2) For each generation, perform the following operations:*

*a)* Construct the neural network using the current parameter combination, input the training data, and compute prediction results.

*b)* Evaluate the fitness of each individual in the population by calculating a fitness function based on the predicted results and the actual risk levels. Each individual corresponds to a neural network, and their fitness is determined by comparing the predicted output of the neural network to the actual values. This comparison can be expressed as either the mean square error (MSE) or root mean square error (RMSE):

$$MSE = \frac{1}{P}\sum_{i=1}^{P}(y_i - y_i)^2 \quad (4)$$

$$RMSE = \sqrt{\frac{1}{P}\sum_{i=1}^{P}(y_i - y_i)^2} \quad (5)$$

Here, $P$ represents the number of training samples, $y_i$ denotes the actual value, and $y_i$ signifies the predicted output value. Our selection for the fitness function is the RMSE.

*c) Identify the optimal* and suboptimal individual positions based on the fitness function values. Update the location of each individual within the population using a roulette strategy to determine the direction of movement while preserving the positions of the optimal and suboptimal individuals.

*3) Repeat step 2* until the termination condition is met (reaching the maximum number of iterations).

*4) Create a neural network* utilizing the optimal parameter combination, input the test data, and generate predictions.

*5) Output the predictions*, specifically the risk level, and assess the model.

The algorithm's flowchart is depicted in Fig. 2.
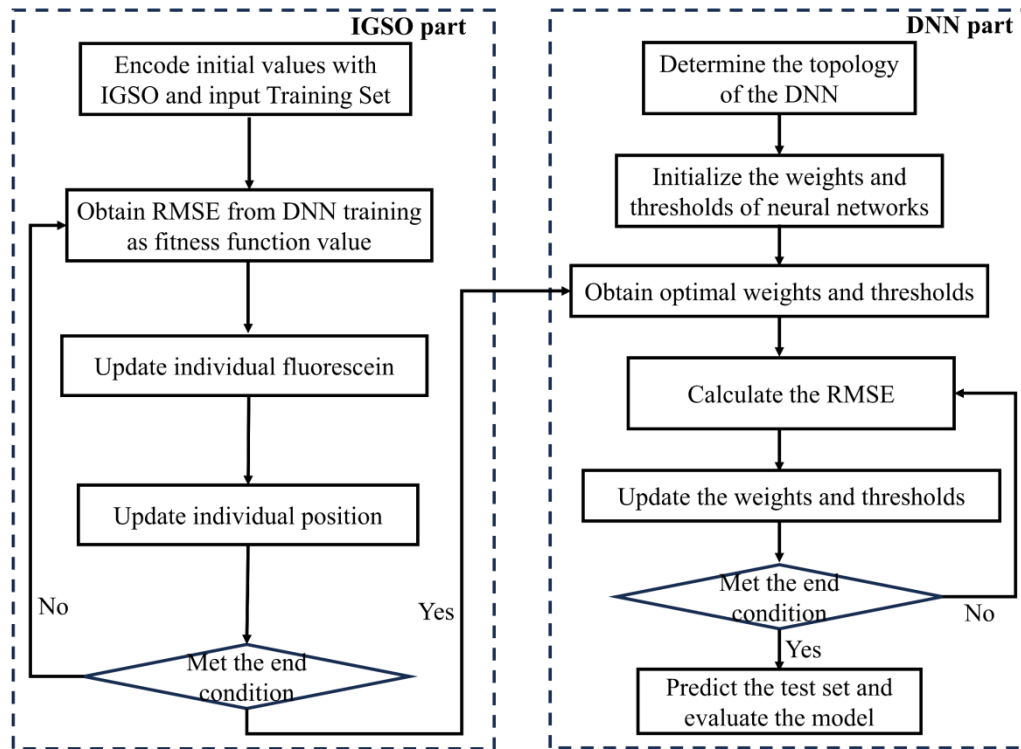


Fig. 2. The flowchart of the algorithm.

## VI. RESULT AND DISCUSSION

In this work, data from 155 rural economic development organizations were selected for the study. Out of these, 110 sets of data were allocated for the training set, while the remaining 45 were used for the test set. For the IGSO algorithm, the number of iterations to 50 and the population size to 35 are set. We train the model using a training set and assess its performance using RMSE. After obtaining a well-trained model, we can input risk-related data from other companies to evaluate the level of risk for the company. Our objective is to have the model predict the company's risk level as accurately as possible, so we aim to obtain a model with a smaller RMSE through training. Our simulation experiments rely on MATLAB 2022b, and we have a high-performance computer system with the following key specifications: CPU is i9-13900KS; GPU is NVIDIA GeForce RTX 4090.

Initially, a combination of DNN and the IGSO algorithm is employed to train the training set. To provide a comparative analysis with the enhanced IGSO algorithm, we also utilized the Whale Optimization Algorithm (WOA) and Particle Swarm Optimization Algorithm (PSO) for optimizing the DNN. Fig. 3.

illustrates the iteration curves of these three optimization algorithms after a single run.

From the Fig. 3, it is evident that the objective function values obtained after iterations using IGSO are superior to those of WOA and PSO, converging to values of 0.01, 0.33, and 0.18, respectively. In terms of convergence speed, IGSO reaches convergence around the 10th generation, which is notably faster than WOA and PSO. This suggests that models optimized through IGSO can provide more accurate predictions for the input training set, and the training speed of the model will also be improved.

To assess the algorithm's stability, a total of 30 runs are conducted and compared the iteration curves of the optimal, worst, and average values for each generation, as depicted in Fig. 4 to Fig. 6. Upon comparing these figures, it becomes evident that IGSO outperforms WOA and PSO in terms of both convergence accuracy and speed. This observation underscores the robust stability of the IGSO algorithm. Across the 30 repeated runs, the average objective function value after convergence was at 0.05, surpassing the respective values of 0.40 for WOA and 0.28 for PSO. This observation underscores the robust stability of the IGSO algorithm.
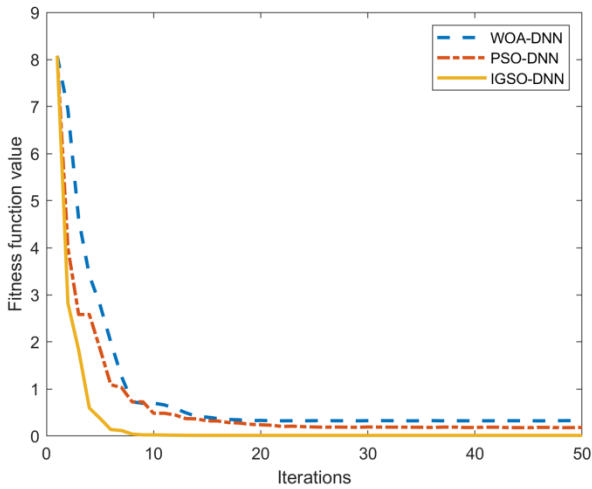
Fig. 3. Plot of iteration curves for one run.
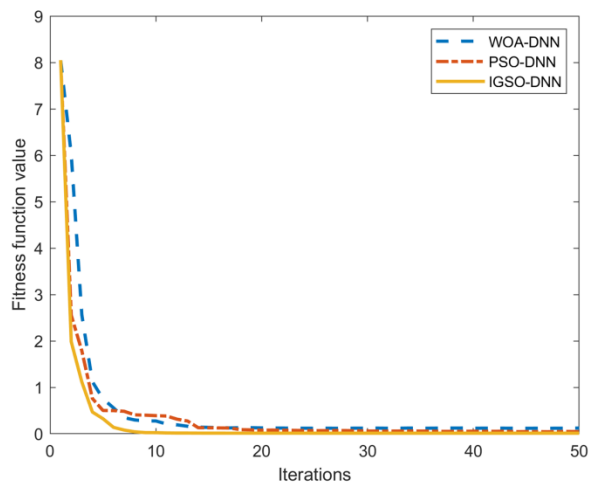


Fig. 4. Iterative curve of optimal values per generation in 30 runs.
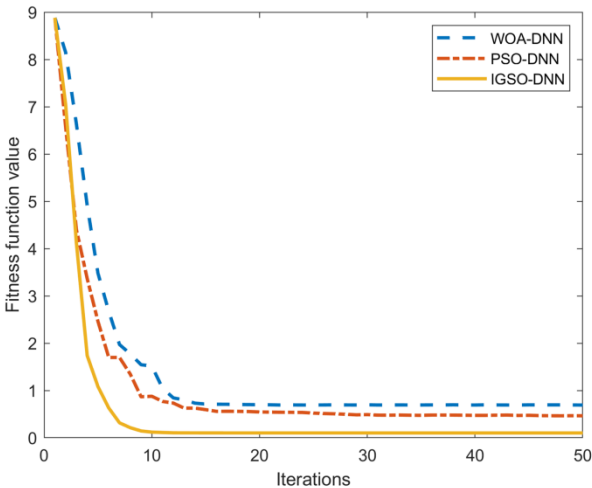


Fig. 5. Iterative curve of worst values per generation in 30 runs.

To evaluate the predictive performance following the successful optimization of DNN parameters using the IGSO optimization algorithm, predictions on a set of 45 test cases are conducted, with the results presented in Fig. 7. Furthermore,

these results with predictions made using DNN optimized are compared through PSO and WOA, as shown in Fig. 8 and Fig. 9. The red line indicates that the true value deviates from the predictive value. Risk level is between 2 and 5.
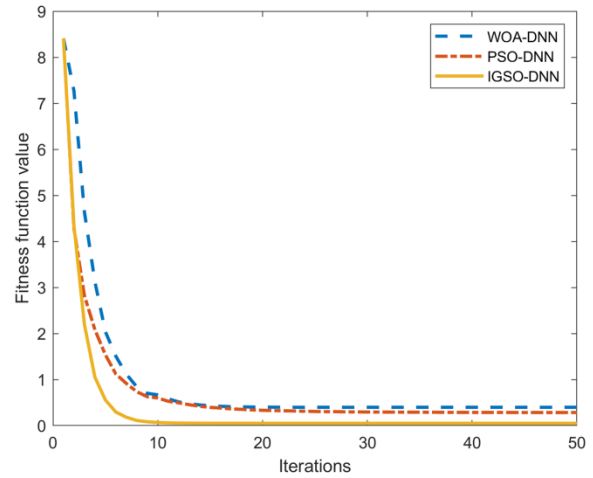


Fig. 6. Iterative curve of mean values per generation in 30 runs.
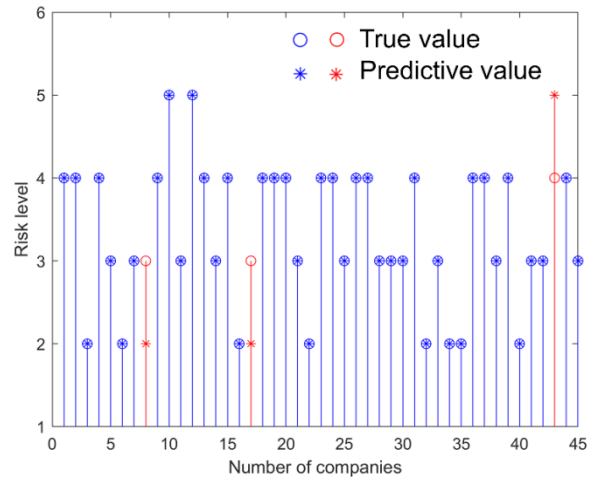


Fig. 7. Plot of true vs. predicted values for test set based on IGSO-DNN.
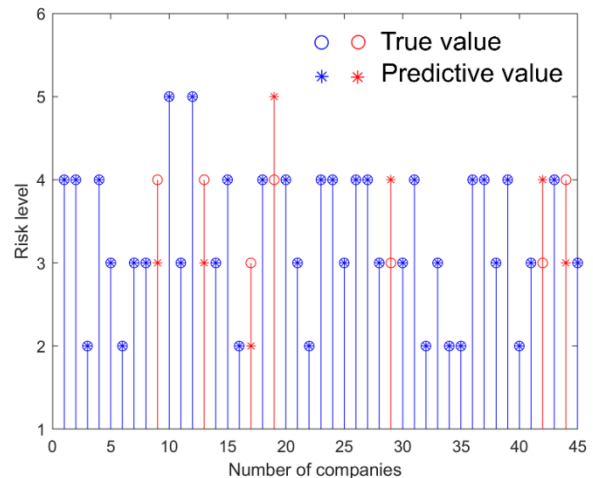


Fig. 8. Plot of true vs. predicted values for test set based on PSO-DNN
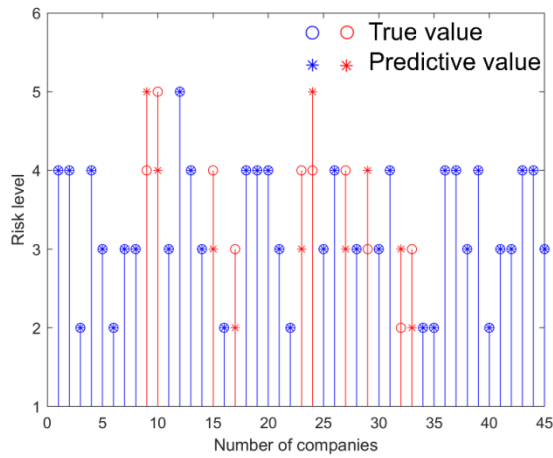
Fig. 9. Plot of true vs. predicted values for test set based on WOA-DNN.

From the results, it is evident that the DNN optimized through IGSO also yields more accurate predictions for the test set. To enhance its demonstrative precision, we further calculated the error count and error rate for risk level predictions using IGSO-DNN, PSO-DNN and WOA-DNN, as summarized in Table III, Table IV, and Table V.

Notably, the IGSO-optimized DNN exhibits superior predictive capabilities, low-medium risk error rate is 12.5% and medium risk error rate is 5.26%, and the remaining risk levels can be accurately predicted. While for PSO-DNN, low-medium risk error rate and medium risk error rate is 18.75% and 21.05%, respectively. For WOA-DNN, its low-risk error rate is 12.5%, low-medium risk error rate is 18.75%, medium risk error rate is 26.32% and medium-high risk error rate is 50%. Compared to WOA-DNN and PSO-DNN, IGSO-DNN exhibits excellent predictive capabilities across various risk ranges.

TABLE III.    RISK PREDICTION RESULTS FOR IGSO-DNN

|  | Safe | Low risk | Low-medium risk | Medium risk | Medium-high risk | High risk |
|---|---|---|---|---|---|---|
| Test sample (True value) | 0 | 8 | 16 | 19 | 2 | 0 |
| Number of errors (Predictive value) | 0 | 0 | 2 | 1 | 0 | 0 |
| Error rate (Predictive value) | 0 | 0 | 12.5% | 5.26% | 0 | 0 |

TABLE IV.    RISK PREDICTION RESULTS FOR PSO-DNN

|  | Safe | Low risk | Low-medium risk | Medium risk | Medium-high risk | High risk |
|---|---|---|---|---|---|---|
| Test sample (True value) | 0 | 8 | 16 | 19 | 2 | 0 |
| Number of errors (Predictive value) | 0 | 0 | 3 | 4 | 0 | 0 |
| Error rate (Predictive value) | 0 | 0 | 18.75% | 21.05% | 0 | 0 |

TABLE V.    RISK PREDICTION RESULTS FOR WOA-DNN

|  | Safe | Low risk | Low-medium risk | Medium risk | Medium-high risk | High risk |
|---|---|---|---|---|---|---|
| Test sample (True value) | 0 | 8 | 16 | 19 | 2 | 0 |
| Number of errors (Predictive value) | 0 | 1 | 3 | 5 | 1 | 0 |
| Error rate (Predictive value) | 0 | 12.50% | 18.75% | 26.32% | 50% | 0 |

## VII. CONCLUSION

This study focuses on the financial risk management issues of rural economic development organizations, focusing on the financial risk management system used for rural economic development organizations, aiming to help rural economic development organizations avoid financial risks. At the same time, an IGSO algorithm was designed to optimize CNN, aiming to improve the accuracy of deep learning algorithms in predicting financial risks. Finally, data from 110 rural economic development organizations were used as a training set, while data from 45 rural economic development organizations were used as a testing set. The simulation results showed that the DNN optimized by IGSO showed excellent predictive ability, with a medium to low-risk error rate of 12.5% and an average accuracy improvement of 3.73% compared to PSO-DNN and WOA-DNN; The medium risk error rate is 5.26%, with an average accuracy improvement of 19.44% compared to PSO-DNN and WOA-DNN; In addition, IGSO DNN can accurately predict other risk levels. In future research, new algorithms will be further developed to improve

the accuracy of predictions. In addition, the applicability of risk prediction models is also a potential research direction.

## REFERENCES

[1] Y. Millo and D. MacKenzie, "The usefulness of inaccurate models: Towards an understanding of the emergence of financial risk management," Accounting, Organizations and Society, vol. 34, no. 5, pp. 638–653, 2009.

[2] L. B. Andersen, D. Häger, S. Maberg, M. B. Næss, and M. Tungland, "The financial crisis in an operational risk management context—A review of causes and influencing factors," Reliability Engineering & System Safety, vol. 105, pp. 3–12, 2012.

[3] G. Wang, G. Chen, H. Zhao, F. Zhang, S. Yang, and T. Lu, "Leveraging Multisource Heterogeneous Data for Financial Risk Prediction: A Novel Hybrid-Strategy-Based Self-Adaptive Method," MIS Quarterly, vol. 45, no. 4, pp. 1949–1998, 2021.

[4] Y. Yang, Y. Qin, Y. Fan, and Z. Zhang, "Unlocking the Power of Voice for Financial Risk Prediction: A Theory-Driven Deep Learning Design Approach," MIS Quarterly, vol. 47, no. 1, pp. 63–96, 2023.

[5] X. Yi, "Application of data mining in enterprise financial risk prediction based on genetic algorithm and linear adaptive optimization," Soft Computing, vol. 27, no. 14, pp. 10305–10315, 2023.

[6] M. Shamsi and P. Cuffe, "A Prediction Market Trading Strategy to Hedge Financial Risks of Wind Power Producers in Electricity

Markets," IEEE Transactions on Power Systems, vol. 36, no. 5, pp. 4513-4523, Sept. 2021.

[7] B. Ofem, B. Arya, and S. P. Borgatti, "The Drivers of Collaborative Success Between Rural Economic Development Organizations," Nonprofit and Voluntary Sector Quarterly, vol. 47, no. 6, pp. 1113–1134, 2018.

[8] S. Ahado, L. Chkhvirkia, and J. Hejkrlik, "Is the Success of Rural Cooperatives Conditioned by the Group Characteristics and Their Value Chain? Evidence from New Farmer Groups in Georgia," European Journal of Development Research, vol. 34, no. 2, pp. 677–702, 2022.

[9] T. R. Popp, P. H. Feindt, and K. Daedlow, "Policy feedback and lock-in effects of new agricultural policy instruments: A qualitative comparative analysis of support for financial risk management tools in OECD countries," Land Use Policy, vol. 103, pp. 105313, 2021.

[10] J. Sun, H. Fujita, P. Chen, and H. Li, "Dynamic financial distress prediction with concept drift based on time weighting combined with Adaboost support vector machine ensemble," Knowledge-Based Systems, vol. 120, pp. 4–14, 2017.

[11] J. Sun, H. Li and H. Adeli, "Concept Drift-Oriented Adaptive and Dynamic Support Vector Machine Ensemble With Time Window in Corporate Financial Risk Prediction," in IEEE Transactions on Systems, Man, and Cybernetics: Systems, vol. 43, no. 4, pp. 801-813, July 2013.

[12] M.-F. Tsai and C.-J. Wang, "On the risk prediction and analysis of soft information in finance reports," European Journal of Operational Research, vol. 257, no. 1, pp. 243–250, 2017.

[13] D. Liang, C.-F. Tsai, A.-J. Dai, and W. Eberle, "A novel classifier ensemble approach for financial distress prediction," Knowledge And Information Systems, vol. 54, no. 2, pp. 437–462, 2018.

[14] C. W. S. Chen, R. Gerlach, E. M. H. Lin, and W. C. W. Lee, "Bayesian Forecasting for Financial Risk Management, Pre and Post the Global Financial Crisis: Bayesian Forecasting for Financial Risk Management," Journal of Forecasting, vol. 31, no. 8, pp. 661–687, 2012.

[15] H. Chen and X. Zhao, "Green financial risk management based on intelligence service," Journal of Cleaner Production, vol. 364, pp. 13261, 2022.

[16] W. Yang, Y. Zhou, W. Xu, and K. Tang, "Evaluate the sustainable reuse strategy of the corporate financial management based on the big data model," Journal of Enterprise Information Management, vol. 35, no. 4/5, pp. 1185–1201, 2022.

[17] X. Li, J. Wang, and C. Yang, "Risk prediction in financial management of listed companies based on optimized BP neural network under digital economy," Neural Computing & Applications, vol. 35, no. 3, pp. 2045–2058, 2023.

[18] Z. Yuanfang, "Optimization of financial market risk prediction system based on computer data simulation and Markov chain Monte Carlo," Soft Computing, 2023.

[19] G. Du and F. Elston, "Financial risk assessment to improve the accuracy of financial prediction in the internet financial industry using data analytics models," Operations Management Research, vol. 15, no. 3–4, pp. 925–940, 2022.

[20] J. Liu, S. Zhang, and H. Fan, "A two-stage hybrid credit risk prediction model based on XGBoost and graph-based deep neural network," Expert Systems With Applications, vol. 195, pp. 116624, 2022.

[21] Y. Peng, G. Wang, G. Kou, and Y. Shi, "An empirical study of classification algorithm evaluation for financial risk prediction," Applied soft computing, vol. 11, no. 2, pp. 2906–2915, 2011.

[22] P. Xia, Z. Ni, X. Zhu, J. Zhang and Y. Jin, "A Novel Prediction Method Based on Improved Binary Glowworm Swarm Optimization and Multi-Fractal Dimension for P2P Lending Investment Risk," IEEE Access, vol. 8, pp. 23232-23245, 2020.

[23] R. Selvanambi, J. Natarajan, M. Karuppiah, S. H. Islam, M. M. Hassan, and G. Fortino, "Retraction Note: Lung cancer prediction using higher-order recurrent neural network based on glowworm swarm optimization," Neural Computing & Applications, vol. 35, no. 4, pp. 3571–3571, 2023.

[24] R. Selvanambi, J. Natarajan, M. Karuppiah, S. H. Islam, M. M. Hassan, and G. Fortino, "Lung cancer prediction using higher-order recurrent

[25] N. Zainal, A. M. Zain, N. H. M. Radzi, and M. R. Othman, "Glowworm swarm optimization (GSO) for optimization of machining parameters," Journal of intelligent manufacturing, vol. 27, no. 4, pp. 797–804, 2016.

[26] J. L. Fernandez-Martinez and E. Garcia-Gonzalo, "Stochastic Stability Analysis of the Linear Continuous and Discrete PSO Models," IEEE Transactions on Evolutionary Computation, vol. 15, no. 3, pp. 405-423, June 2011.

[27] J. Chen, Y. Wu, X. Xu, H. Zheng, Z. Ruan and Q. Xuan, "PSO-ANE: Adaptive Network Embedding With Particle Swarm Optimization," IEEE Transactions on Computational Social Systems, vol. 6, no. 4, pp. 649-659, Aug. 2019.

[28] H. Pang et al., "Design of Highly Uniform Field Coils Based on the Magnetic Field Coupling Model and Improved PSO Algorithm in Atomic Sensors," IEEE Transactions on Instrumentation and Measurement, vol. 71, pp. 1-11, 2022.

[29] M. R. AlRashidi and M. E. El-Hawary, "A Survey of Particle Swarm Optimization Applications in Electric Power Systems," IEEE Transactions on Evolutionary Computation, vol. 13, no. 4, pp. 913-918, Aug. 2009.

[30] H. Ma, T. Wang, Y. Li and Y. Meng, "A Time Picking Method for Microseismic Data Based on LLE and Improved PSO Clustering Algorithm," IEEE Geoscience and Remote Sensing Letters, vol. 15, no. 11, pp. 1677-1681, Nov. 2018.

[31] D. Liu, Z. Deng, X. Mao, Y. Yang and E. I. Kaisar, "Two-Echelon Vehicle-Routing Problem: Optimization of Autonomous Delivery Vehicle-Assisted E-Grocery Distribution," IEEE Access, vol. 8, pp. 108705-108719, 2020.

[32] N. Priyadarshi, M. S. Bhaskar and D. Almakhles, "A Novel Hybrid Whale Optimization Algorithm Differential Evolution Algorithm-Based Maximum Power Point Tracking Employed Wind Energy Conversion Systems for Water Pumping Applications: Practical Realization," in IEEE Transactions on Industrial Electronics, vol. 71, no. 2, pp. 1641-1652, Feb. 2024.

[33] R. Liu, Z. Liang, Z. Wang and W. Li, "Indoor Visible Light Positioning Based on Improved Whale Optimization Method With Min-Max Algorithm," in IEEE Transactions on Instrumentation and Measurement, vol. 72, pp. 1-10, 2023.

[34] F. S. Gharehchopogh and H. Gholizadeh, "A comprehensive survey: Whale Optimization Algorithm and its applications," Swarm and Evolutionary Computation, vol. 48, pp. 1–24, 2019.

[35] Q. -V. Pham, S. Mirjalili, N. Kumar, M. Alazab and W. -J. Hwang, "Whale Optimization Algorithm With Applications to Resource Allocation in Wireless Networks," IEEE Transactions on Vehicular Technology, vol. 69, no. 4, pp. 4285-4297, April 2020.

[36] X. Zhou, Y. Gao, C. Li and Z. Huang, "A Multiple Gradient Descent Design for Multi-Task Learning on Edge Computing: Multi-Objective Machine Learning Approach," in IEEE Transactions on Network Science and Engineering, vol. 9, no. 1, pp. 121-133, 1 Jan.-Feb. 2022.

[37] S. Liu and L. N. Vicente, "Accuracy and fairness trade-offs in machine learning: a stochastic multi-objective approach," Computational Management Science, vol. 19, no. 3, pp. 513–537, 2022.

[38] S. Kim, I. Kim, and D. You, "Multi-condition multi-objective optimization using deep reinforcement learning," Journal of Computational Physics, vol. 462, pp. 111263, 2022.

[39] C. Tian, T. Niu, and W. Wei, "Volatility index prediction based on a hybrid deep learning system with multi-objective optimization and mode decomposition," Expert Systems With Applications, vol. 213, pp. 119184, 2023.

[40] J. Wu, "Improved Drosophila Visual Neural Network Application in Vehicle Target Tracking and Collision Warning," International journal of advanced computer science & applications, vol. 14, no. 8, 2023.

[41] M. Nair, M. I. Marie, and L. A. Abd-Elmegid, "Prediction of Cryptocurrency Price using Time Series Data and Deep Learning Algorithms," International journal of advanced computer science & applications, vol. 14, no. 8, 2023.

678 | P a g e

# Sustainable Smart Home IoT to Open and Close the House Fence using a Scanning Method

Heri Purwanto[1], Rikky Wisnu Nugraha[2], Fahmi Reza Ferdiansyah[3], Deshinta Arrova Dewi[4], Rudy Sofian[5],
Muhammad Faridh Rizaldy[6]

Department of Information Systems, University of Sangga Buana, Bandung, Indonesia[1]
Faculty of Information and Digital Technology, Institut Digital Ekonomi, LPKIA, Bandung, Indonesia[2, 3, 5, 6]
Faculty of Data Science and Information Technology-INTI International University, Nilai, Malaysia[1, 4]

*Abstract*—A home that is connected to the Internet allows all of its appliances and systems to communicate with one another via the Internet of Things (IoT), making it a component of a sustainable smart home. The issue with this study's findings is that some homes still utilize manual gates, which must be opened and closed by pushing a gate. Considering that a building's gate is its primary form of security, this is viewed as being less effective. Additional locks are required on the fence to overcome its frail defenses, which do not deter criminals. This project aims to create a smart home by using the internet to automate the process of opening and closing home gates based on IoT. Prototyping is a strategy used in software development, whereas card barcode objects are found using scanning. The findings demonstrated that Radio Frequency Identification (RFID), which is connected to a smartphone as a communication medium between the device and the user, is connected to each other between the microcontroller and the stepper motor so that it can operate the home gate automatically. The test findings indicate that when the user taps in the RFID card as the drive for the gate, the reaction time of the RFID to the stepper is between 7.35 and 10.10 seconds. Future research can use long-range RFID technology, which has a reading distance of more than 5-12 meters with a radio frequency band refarming process of 800 - 900 Mhz for any smart home or smart building. The accuracy of reading RFID cards with an RFID reader is about 1 - 5 cm, which is the limitation in this study. According to the test findings, it can be said that the development of an automatic fence control system increases the effectiveness of home security and allows for direct control from a smartphone. Using a Long-RFID instrument with a reading precision distance of 5–12 meters and a radio frequency band refarming method of 800–900 Mhz is anticipated to be sustainable in this research.

*Keywords*—*Smart home; Internet of Things (IoT); Radio Frequency Identification (RFID); scanning; sustainable smart home; smart city; process innovation*

## I. Introduction

A house is a structure that people occupy as their place of residence for a while. The primary purpose of the house is to offer a place to unwind after returning from work. When you get home from work, you're exhausted, and your house is a cozy place to unwind. This home is used as a communal living space for friends or family [1]. In keeping with the world's rapid technological development, the idea of a home started to be combined with modern technology to make people feel comfortable, safe, and simple while performing various activities there. These concepts are highly sought-after and

have become a mainstay for the type of modern home, and they are known as the concept of a "smart home" [2]. In order for a fence or house door to open and close automatically, a smart home connects a communication network with it through a microcontroller [3].

The goal of the smart home concept is to make it comfortable for the homeowner to be able to manage and watch over their home even when they are not at home [4]. A house can be said as a smart home if the house's equipment can be connected to the Internet because the Internet is part of the rapidly growing technological developments in people's lives today that are capable of being used as a medium of communication and control of devices remotely as long as they are still connected to each other [5].

With the advancement of Internet infrastructure, a variety of real objects, such as electronic devices, human-useable equipment, and any other real object, will be able to connect to the Internet. This concept is known as the "Internet of Things" in the "IT" industry [6]. The Internet of Things (IoT) is a system made up of intelligent gadgets like sensors, actuators, and microcontrollers that enable automatic information exchange and communication. Smart equipment, such as smart home devices and smart classrooms, are created by combining a number of sensors, actuators, and microcontrollers that support communication between devices as part of the Internet of Things (IoT) [7].

The Internet of Things is a concept that has the aim of expanding the use of the Internet that is connected continuously which is connected to physical objects that are capable of sharing data and remotely affecting physical objects through the Internet network [8]. IoT can integrate uniquely identified embedded computing devices in the existence of internet infrastructure, it can be concluded that IoT basically connects the Embedded System to the Internet [9].

Embedded systems can be used to implement IoT devices because they frequently conserve energy. The Wemos D1 Microcontroller is one of the remote controller technologies with ARM-based embedded systems (Advanced RISC Machine) [10]. A highly effective device that can control tools is the Wemos D1 Microcontroller. Wemos is an electronic device module that works with Arduino and is based on the Wemos D1, so projects that specifically use the IoT concept frequently use this module [11].

The issue with this study's gate system is that it is still operated manually, with the door still having to be pushed open and shut. As a result, the gate system is not yet functional. The fence uses an additional key to overcome the weak security that allows criminals to evade it, and the gate is the primary security measure for securing a building. The growing need for technology has made everyone dependent on it, and one way this is done is by using it to simplify tasks.

A car gate will also be developed as part of this study, and it will function automatically based on the presence of a car detected by ultrasonic sensors. The tool that will be developed uses a controller, specifically a microcontroller, which is a computer system device that is used to control the system. The alternative to this automatic fence is using an Android smartphone. This study takes the object of congestion on the Pesona Prima Citapen Housing Complex, West Bandung Regency – West Java – Indonesia as a case study. Usually, when a car or motorcycle enters or exits a home, there is congestion. This occurs as a result of the person having to manually open and close a house fence. With an automatic fence system at home, it is hoped that there won't be any more traffic jams in neighborhoods because a car or motorcycle can drive right into the yard without the driver getting out; all they have to do is get closer to the house fence, at which point the fence will automatically open, shortening the wait time and reducing the line of cars behind them.

Based on previous research, the implementation of smart homes can be done by everyone because smart homes have the advantage of always controlling the condition of the house [12]. The purpose of the smart home concept is to provide comfort to the homeowner [13]. To be able to control and monitor his home [14]. Smart homes can also minimize a person at times such as forgetting to lock the door [15], forgetting to turn off the lights [16], forgetting to turn off the television, or [17] forgetting other electronic items [18], thus making the house unsafe [19] and also having an impact on the waste of energy [20]. The smart home concept pays attention to the efficiency of electrical energy use [21]. The use of this smart home can also make it easier for users to control household electronic equipment such as lights [22], Air Conditioner [23] , and Televisions [24]. So that it can reduce the wastage of electricity [25], and is one of the efforts to develop a sustainable smart home.

Along with the development of Internet infrastructure [26], in the field of "IT", this concept has been known as the "Internet of Things" [27]. The Internet of Things (IoT) is a development of network communication of interrelated objects [28] and connected to each other via Internet communication [29], which is useful for exchanging data and information [30]. Research in the IoT field is very rapid because it has become part of human life because almost all sectors of human life use IoT technology [10]. Like the automatic gate that can open and close through the press of the remote control [9], smartphone [8], fingerprint, which is controlled by humans [7]. The tool to be developed uses a controller, namely a microcontroller [5]. Wemos D1 also has advantages compared to other microcontrollers [3], starting from more pin outs and analog pins [2], [31], larger memory, and low energy Bluetooth 4.0 [21]. On the wemos D1 microcontroller there is a WiFi module

available in a dual core processor chip that runs on Xtensa LX16 instructions so that it is very supportive for creating Internet of Things application systems and can send notifications to various communication tools such as smartphone [3], [20]. Some previous research has not been integrated with the design of using applications on smartphones [19].

Based on the previous research mentioned above, WemosD1 microcontroller technology, RFID Readers, and smartphone-connected applications are still receiving relatively little attention from researchers, making this a research gap that needs to be investigated further. This study used the smartphone feature as a security system on the fence by utilizing the Wemos D1 microcontroller, along with a car garage door, to develop an automatic gate controller that operates automatically based on the presence of a car detected by RFID. The Wemos D1 microcontroller can send brief messages to smartphones whenever the door opens and when the door closes.

## II. METHOD

The following steps must be taken in order to conduct research and solve the problem:

### A. Methodology of System Development

In order to create a new system or enhance an existing one, the prototyping method is used [32]. Due to the method's focus on the analysis, design, and implementation phases, which are three very important stages in creating or improving the system [33]. The emphasis of the method which will be repeated continuously involving collaboration with users will produce a prototype of the system that will be reviewed before heading to the implementation of the system that has been desired by the user [34]. In the prototype method, there are several stages to start system development [35], as presented in Fig. 1.
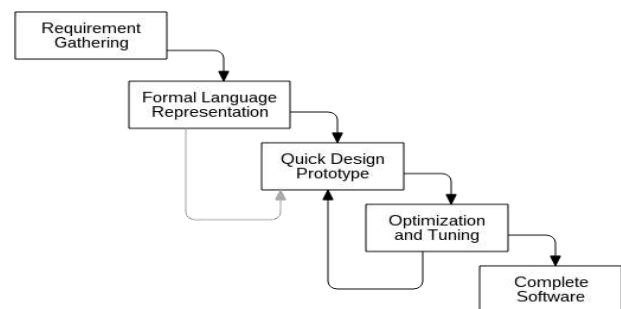


Fig. 1. Prototype Approach. (Source: https://www.ekrut.com/media /prototype Accessed on July 23, 2022, at 21:10 WIB).

In Fig. 1, there are five stages, namely the prototyping stage or the requirements gathering phase, which explains that users and analysts have a meeting and then have a conversation between them [36]. Analysts use the results of the requirements-gathering phase as the foundation for the idea (concept) of developing a program or system, and at this stage, the analyst also converts the obtained specifications into concepts that are simple to understand [34]. The analyst will also perform quick planning and modeling in the form of a quick design before beginning the construction of prototype making [37]. The program that has been created is based on the

prototype that has been submitted and agreed upon together (the analyst team), then at this stage, a program is also tested by the analyst and of course the user, then the user assesses whether the program can be accepted or not [35]. The user has approved the program (it successfully complies with the suggested specifications), so the user can successfully use the ordered program [32].

### B. Scanning Method

The Scanning method of system design in this study makes use of object detection. The process of finding objects, whether they move or not, like people or things, is known as object detection [38]. Object tracking, which aims to identify or track the position of moving objects in an image sequence, is one application of image processing that can be used in daily life [39]. With this object detection, it is expected to be able to predict and determine the position on the frame that shows where the object is [40]. Object detection has the advantage of detecting an object's movement. [41]. The utilization of Computer Vision and Image Processing technology to detect objects can make it easier for humans to detect objects [42], for example in the field of security. Object tracking can use the Scanning method [43].



Fig. 2.   Scanning Process ((Source: Accessed on July 23, 2022 at 21:20 WIB).

The scanning method is a reading technique to get information without reading the others [44]. It is directly to the problem sought, namely specific facts and certain information [45]. Scanning is also known as reading scan. Scanning is reading very fast [46]. Speed reading means reading that prioritizes speed without ignoring its understanding [47]. Usually, speed is associated with the reader's goals, needs, and reading material [39]. Fig. 2 shows the scanning process.

### C. Data Collection Techniques

The first data collection technique was conducted by interviewing sources by holding meetings and giving questions to sources [48], both orally and in writing at least two individuals [49], who directly met to obtain information [50], from the first-hand (primary) [51], in accordance with other selection methods [52], examined the results of selecting different information [53]. The second data collection technique is observation to obtain the required data [54], this method is considered the most effective [55] because researchers go directly to the research location [56]–[58]. While the third is to provide a questionnaire for the information sorting procedure [59], which is done by giving a group of questions [60], which are arranged for respondents to answer [61], either given face to face [62] or via the web [43].

## III.   RESULT AND DISCUSSION

This research is based on a phenomenon that occurs, which can cause several problems that often occur in house fences, namely: 1) There is often congestion on residential streets in the morning because many vehicles come out of the house that the owner has to get out of the vehicle again to close the fence, 2) The occurrence of noise / disturbing neighbors at night to call people in the house to open the fence by using a car horn. Therefore, a solution is needed to deal with the problems that are happening, namely the need for a Smart Home system on the fence that aims to: 1) Knowing people who come in and out of the house because it is connected to smartphone notifications, 2) Opening and closing the fence can automatically make it easier for residents of the house and its surroundings, and 3) Minimize congestion in the morning when the residents of the house crawl to work.

The construction of the smart home system on the fence is a system that is used to automatically open and close the gate of the house fence. This system combines several RFID readers on the house fence into a single control unit, and it is combined with a microcontroller that has been programmed in the Arduino IDE programming language. Because of the design of this system, the user can control, monitor, and manage to open and close the fence as needed. This system is controlled by a reader that can scan an RFID card as well as an internet-connected application on an Android device for every arrangement and control of the fence, allowing for remote control of the system.

There are several requirements for this system's construction, both technically and in terms of use, before this automatic fence can be used. With an RFID card, not everyone can enter the house, but only a registered RFID card can open the house's fence. To prevent card misuse, this RFID will generate a user ID when it is used. In reality, this system will carry out orders in accordance with the usage guidelines.

The following is the flow in the Smart Home system: 1) Opens the gate of the house with an RFID reader that can scan the card, 2) The gate can open if the RFID card matches its unique code, 3) The smart home system can be controlled by an internet-connected android which sends notifications to smartphones.

### A. System Architecture

Based on Fig. 3 above, describes the system that was built, where the user taps in the card to the RFID reader to enter the house. Furthermore, the Wemos microcontroller processes the stepper motor to open the fence so that the vehicle can enter the garage. The fence will close by itself when there are no obstacles around it.

### B. System Modeling

System modeling is a set of activity processes that can describe clearly and in detail how the system will run [63]. The purpose of modeling this system is to explain, simplify, and evaluate the system to be built [64]. In this research, the system modeling uses UML (Unified Modeling Language) diagrams to describe the working system [65]. The UML models used include Use Case Diagrams and Flow Chart Diagrams [66]. A use case diagram is a depiction process carried out to show the

relationship between the user and the designed system [67]. The results of the representation of the scheme are made in a simple manner and aim to make it easier for the user to read the information provided [68]. The use case is included in the UML (Unified Modeling Language) diagram, and the manufacturing process itself is carried out before we enter the DFD (Data Flow Diagram) concept design [69]. A flowchart diagram is a diagram that displays the steps and decisions to carry out a process of a program [70]. Each step is depicted in the form of a diagram and is connected by a line or arrow direction [71]. Flowcharts play an important role in deciding a step or functionality of a programming project that involves many people at once [72].
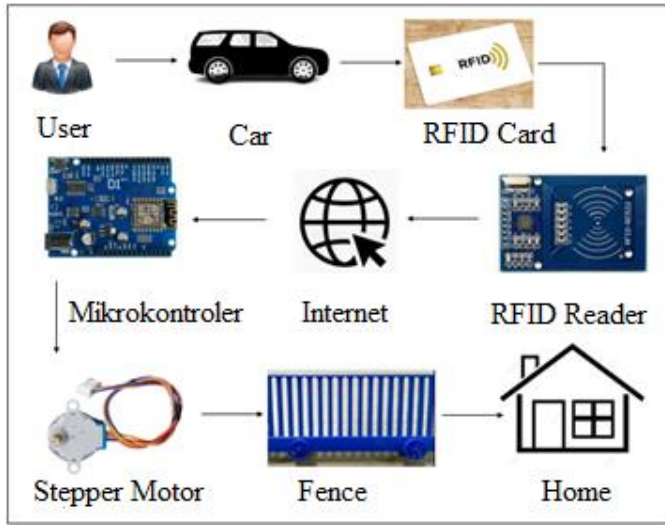


Fig. 3. System architecture.
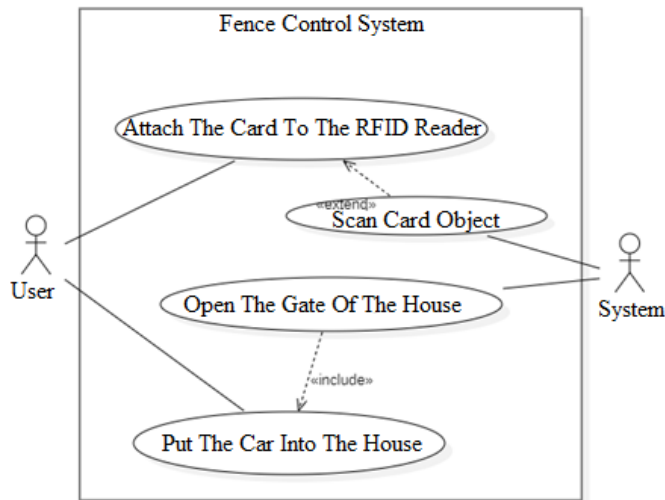


Fig. 4. Use case diagram of fence control system.

Based on Fig. 4, it can be explained that the user who will enter the house must have an RFID card that is useful for entering the house, the system scans the object of the card to open the fence and sends a message to the user's smartphone.

Based on Fig. 5 The flowchart above shows that the scanned RFID card must match the ID tag of each registered card, if the card is registered and matches the microcontroller

will drive the stepper motor and the fence will open, if the RFID card does not match the ID tag then the microcontroller will not turn on stepper motor and the fence will not open.
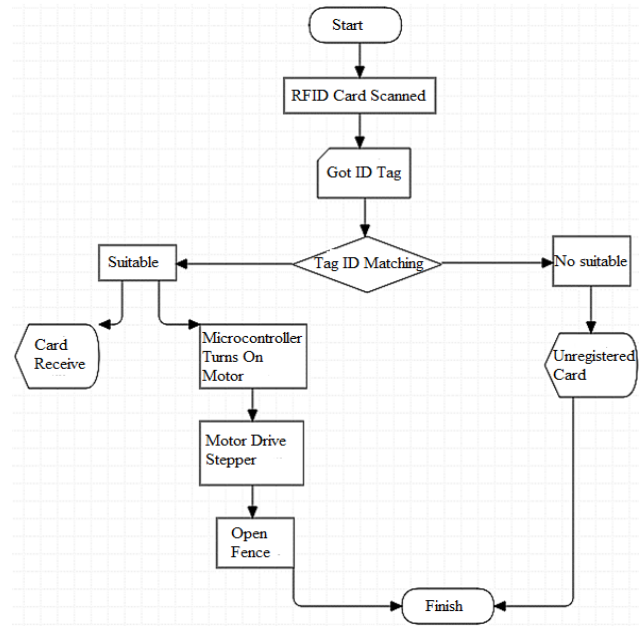


Fig. 5. Flowchart diagram of fence control system.

### C. System Circuit

There are two data output pins directly connected to the circuits in the automation system and ten input pins used in this microcontroller circuit. This pin is attached to both the RFID reader and the fence motor, which controls fence movement (see Fig. 6).
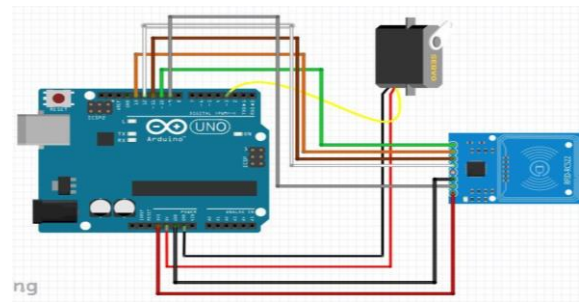


Fig. 6. Fence control system circuit.



Fig. 7. Wemos D1 microcontroller.

Data from the input device is controlled and processed by the Wemos D1 microcontroller (see Fig. 7) before being sent to the output device. Wemos differs from other Wi-Fi modules in that it has a microcontroller that can be programmed via a serial port, allowing for programming of the device without the need for any additional modules. The Wemos D1 microcontroller is used to connect various systems, such as ultrasonic sensors and RFID readers, which can be used as links to drive stepper motors, making it easier for users to control various electronic devices.



Fig. 8. Fence circuit.

In this prototype fence as shown in Fig. 8, it is driven by a stepper motor which functions to rotate and direct objects at certain angles or distances. This is made possible by a combination of an ordinary motor and an additional sensor in the form of an encoder for position feedback. The controller of the stepper motor, better known as the stepper drive, is the most important and sophisticated part of a stepper motor, because it is designed for high precision.
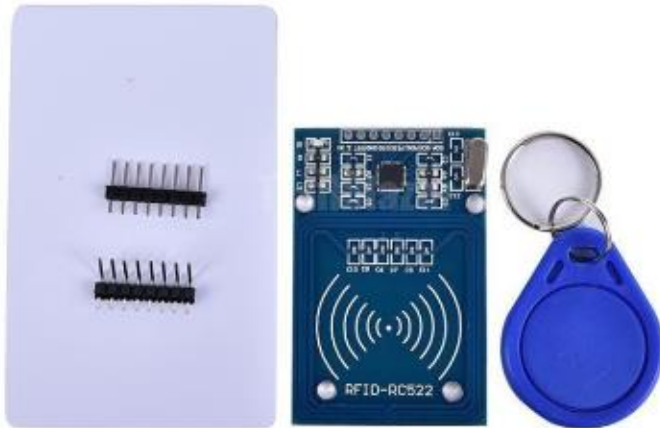


Fig. 9. Fence control system circuit.

Radio frequency waves are used in the data transmission process by Radio Frequency Identification (RFID). The RFID tag and the RFID reader, which are both included in the device, wirelessly exchange data during the transmission process.

### D. System Test

There will be five RFID cards registered in this automatic fence system. When an RFID card is read, there is an open

fence between the RFID reader and the card, so RFID testing aims to measure this distance. The RFID card is tested by moving it closer to the available RFID reader. A centimeter scale is used to calculate the separation between the RFID reader and the RFID card.

TABLE I. RFID CARD SYSTEM TESTING TABLE

| Trials | RFID Card Reading Distance | Fence |
|---|---|---|
| 1 | 1 cm | Open |
| 2 | 2 cm | Open |
| 3 | 3 cm | Open |
| 4 | 4 cm | Open |
| 5 | 5 cm | Open |
| 6 | 6 cm | Closed |
| 7 | 7 cm | Closed |
| 8 | 8 cm | Closed |
| 9 | 9 cm | Closed |
| 10 | 10 cm | Closed |

The reading distance between the RFID reader and the RFID card is shown in the Table I to be between 1 and 5 cm. The RFID card cannot be read if it is brought closer to the RFID reader than five centimeters away.

The RFID test when entering the house is carried out when the user taps the RFID card into the RFID reader located around the gate of the house.

TABLE II. FENCE TIME RESPONSE TABLE

| Trials | RFID Card Owner | Response Time Fence |
|---|---|---|
| 1 | Card 1 | 7.92 Seconds |
| 2 | Card 2 | 8.55 Seconds |
| 3 | Card 3 | 7.35 Seconds |
| 4 | Card 4 | 9.05 Seconds |
| 5 | Card 5 | 10.10 Seconds |

In Table II, it can be seen that the response time of the fence obtained on each RFID card is almost the same.

### IV. CONCLUSIONS

The following conclusions can be made based on the outcomes of the tests conducted on the prototype fence: First, the designed fence can be made to open and close automatically using an RFID controller. With this controller, the homeowner only needs to move the vehicle closer and connect the RFID card to the RFID reader to open and close the fence rather than climbing up and down the vehicle. For smart homes, using an RFID controller is much better than using an Android base application because, with RFID, the user can store the RFID card in the car, which is undoubtedly more efficient than using a smartphone, whereas with Android, the user must carry the Android smartphone with him every time he leaves the house. In order to inform homeowners about who enters and leaves the house, the automatic fence can be connected to smartphones as a notification medium. Smartphone notifications are much more effective than LED notifications on the front of the house because smartphones can be remotely controlled. Second, the test findings indicate that

when the user taps in the RFID card as the drive for the gate, the reaction time of the RFID to the stepper is between 7.35 and 10.10 seconds fence gates. Thirdly, the congestion that frequently develops in apartment complexes can be reduced by the installation of automatic fence gates.

If the automatic fence's controller (see Fig. 9) uses sensors that can be connected to one another, like Long-RFID, which has a reading accuracy distance of 5 to 12 meters and a radio frequency band refarming process of 800 to 900 Mhz, future research will be much better.

## REFERENCES

[1] M. D. Putro and F. D. Kambey, "Sistem Pengaturan Pencahayaan Ruangan Berbasis Android pada Rumah Pintar," J. Nas. Tek. Elektro, vol. 5, no. 3, pp. 297–307, 2016.

[2] Herdianto, "Perancangan Smart Home dengan Konsep Internet of Things ( IoT ) Berbasis Smartphone," Ilm. Core It, vol. 6, no. x, pp. 120–130, 2018.

[3] M. Muslihudin, W. Renvilia, Taufiq, A. Andoyo, and F. Susanto, "Implementasi Aplikasi Rumah Pintar Berbasis Android Dengan Arduino Microcontroller," J. Keteknikan dan Sains, vol. 1, no. 1, pp. 23–31, 2018.

[4] M. A. Hoque and C. Davidson, "Design and implementation of an IoT-based smart home security system," Int. J. Networked Distrib. Comput., vol. 7, no. 2, pp. 85–92, 2019.

[5] S. Zheng, N. Apthorpe, M. Chetty, and N. Feamster, "User perceptions of smart home IoT privacy," Proc. ACM Human-Computer Interact., vol. 2, no. CSCW, 2018.

[6] T. Hargreaves, C. Wilson, and R. Hauxwell-Baldwin, "Learning to live in a smart home," Build. Res. Inf., vol. 46, no. 1, pp. 127–139, 2018.

[7] S. Monteith, T. Glenn, J. Geddes, E. Severus, P. C. Whybrow, and M. Bauer, "Internet of things issues related to psychiatry," Int. J. Bipolar Disord., vol. 9, no. 1, 2021.

[8] G. Baldini, M. Botterman, R. Neisse, and M. Tallacchini, "Ethical Design in the Internet of Things," Sci. Eng. Ethics, vol. 24, no. 3, pp. 905–925, 2018.

[9] G. Lampropoulos, K. Siakas, and T. Anastasiadis, "Internet of Things in the Context of Industry 4.0: An Overview," Int. J. Entrep. Knowl., vol. 7, no. 1, pp. 4–19, 2019.

[10] M. S. Ali, M. Vecchio, M. Pincheira, K. Dolui, F. Antonelli, and M. H. Rehmani, "Applications of Blockchains in the Internet of Things: A Comprehensive Survey," IEEE Commun. Surv. Tutorials, vol. 21, no. 2, pp. 1676–1717, 2019.

[11] A. Raj and D. Steingart, "Review—Power Sources for the Internet of Things," J. Electrochem. Soc., vol. 165, no. 8, pp. B3130–B3136, 2018.

[12] A. Hildayanti and M. S. Machrizzandi, "Sistem Rekayasa Internet Pada Implementasi Rumah Pintar Berbasis IoT," J. Ilm. Ilmu Komput. Fak. Ilmu Komput. Univ. Al Asyariah Mandar, vol. 6, no. 1, pp. 45–51, 2020.

[13] Z. A. Achmad and R. Ida, "Etnografi Virtual Sebagai Teknik Pengumpulan Data Dan Metode Penelitian," J. Soc. Media, vol. 2, no. 2, p. 130, 2018.

[14] O. A. A. Mahmoud, S. Hadad, and T. A. Sayed, "The association between Internet addiction and sleep quality among Sohag University medical students," Middle East Curr. Psychiatry, vol. 29, no. 1, pp. 0–5, 2022.

[15] G. Ji, "Kuaishou short video social network from the perspective of urban-rural cultural linkage: a field study on the mobile internet practices of young Monguor villagers in China's Qinghai Province," Int. J. Anthropol. Ethnol., vol. 5, no. 1, pp. 1–14, 2021.

[16] D. M. Abdel-Salam, H. I. Alrowaili, H. K. Albedaiwi, A. I. Alessa, and H. A. Alfayyadh, "Prevalence of internet addiction and its associated factors among female students at Jouf University, Saudi Arabia," J. Egypt. Public Health Assoc., vol. 94, no. 1, pp. 1–8, 2019.

[17] O.-P. Hilmola, A. Tolli, and A. Kiisler, "Internet page content analysis of north European Sea ports," J. Shipp. Trade, vol. 5, no. 1, 2020.

[18] L. Wang and C. Liu, "Lost in mobile? Exploring the mobile internet digital divide among Chinese college students," Int. J. Educ. Technol. High. Educ., vol. 18, no. 1, 2021.

[19] A. A. Alzalabani and S. M. Eltaher, "Perceptions and reasons of E-cigarette use among medical students: an internet-based survey," J. Egypt. Public Health Assoc., vol. 95, no. 1, 2020.

[20] S. Affouneh, F. A. Mahamid, D. Z. Berte, A. Z. Shaqour, and M. Shayeb, "The efficacy of a training program for social skills in reducing addictive Internet behaviors among Palestinian university students," Psicol. Reflexão e Crítica, vol. 34, no. 1, 2021.

[21] D. Rozgonjuk, K. Täht, and K. Vassil, "Internet use at and outside of school in relation to low- and high-stakes mathematics test scores across 3 years," Int. J. STEM Educ., vol. 8, no. 1, 2021.

[22] M. Liang, "A study of the labor process from a technology transformation perspective: the case of internet virtual teams," J. Chinese Sociol., vol. 8, no. 1, 2021.

[23] X. Yin, Z. Meng, X. Yi, Y. Wang, and X. Hua, "Are 'Internet+' tactics the key to poverty alleviation in China's rural ethnic minority areas? Empirical evidence from Sichuan Province," Financ. Innov., vol. 7, no. 1, 2021.

[24] E. T. de Camargo, F. A. Spanhol, and Á. R. Castro e Souza, "Deployment of a LoRaWAN network and evaluation of tracking devices in the context of smart cities," J. Internet Serv. Appl., vol. 12, no. 1, 2021.

[25] A. Shafarenko, "Indexing structures for the PLS blockchain," Cybersecurity, vol. 4, no. 1, 2021.

[26] K. Ogawa et al., "Proposal for a layer-based IoT construction method and its implementation and evaluation on a rolling stand-up walker," ROBOMECH J., vol. 7, no. 1, 2020.

[27] A. Villanueva et al., "Towards modeling of human skilling for electrical circuitry using augmented reality applications," Int. J. Educ. Technol. High. Educ., vol. 18, no. 1, 2021.

[28] T. Witt, A. Mondschein, J.-P. Majschak, and M. Meyer, "Heat development at the knife roller during leather shaving," J. Leather Sci. Eng., vol. 3, no. 1, 2021.

[29] A. Shafarenko, "A PLS blockchain for IoT applications: protocols and architecture," Cybersecurity, vol. 4, no. 1, 2021.

[30] T. Hidayat, "Internet of Things Smart Agriculture on ZigBee: A Systematic Review," J. Telekomun. dan Komput., vol. 8, no. 1, p. 75, 2017.

[31] J. Guerrero-Ibáñez, S. Zeadally, and J. Contreras-Castillo, "Sensor technologies for intelligent transportation systems," Sensors (Switzerland), vol. 18, no. 4, pp. 1–24, 2018.

[32] A. Syarifudin and N. Ani, "Perancangan Sistem Informasi Pengajuan dan Pelaporan Pembayaran Tunjangan Kinerja Kementerian Keuangan Menggunakan Metode Prototype," J. Sisfokom (Sistem Inf. dan Komputer), vol. 8, no. 2, pp. 149–158, 2019.

[33] Y. A. Prasetyo, N. Ambarsari, P. Studi, S. Informasi, and U. Telkom, "Pengembangan Web E-Commerce Bojana Sari Menggunakan Metode Prototype," vol. 2, no. 1, pp. 1042–1056, 2015.

[34] S. Nurajizah, "Sistem Informasi Perpustakaan Berbasis WEB dengan Metode Prototype: Studi Kasus Sekolah Islam Gema Nurani Bekasi," Am. J. Roentgenol., vol. 179, no. 6, pp. 1643–1644, 2015.

[35] E. Kurniawan and A. K. Syahputra, "Perancangan Aplikasi Pemesanan Dan Pembayaran Berbasis Desktop Pada Percetakan UD. AZKA GEMILANG Menggunakan Metode Prototype," Semin. Nas. Raya, vol. 9986, no. September, pp. 105–110, 2018.

[36] S. Siswidiyanto, A. Munif, D. Wijayanti, and E. Haryadi, "Sistem Informasi Penyewaan Rumah Kontrakan Berbasis Web Dengan Menggunakan Metode Prototype," J. Interkom J. Publ. Ilm. Bid. Teknol. Inf. dan Komun., vol. 15, no. 1, pp. 18–25, 2020.

[37] P. Yoko, R. Adwiya, and W. Nugraha, "Penerapan Metode Prototype dalam Perancangan Aplikasi SIPINJAM Berbasis Website pada Credit Union Canaga Antutn," J. Ilm. Merpati (Menara Penelit. Akad. Teknol. Informasi), vol. 7, no. 3, p. 212, 2019.

[38] J. Lazar et al., "Short-range six-axis interferometer controlled positioning for scanning probe microscopy," Sensors (Switzerland), vol. 14, no. 1, pp. 877–886, 2014.

[39] S. Tadakaluru, W. Thongsuwan, and P. Singjai, "Stretchable and flexible high-strain sensors made using carbon nanotubes and graphite films on natural rubber," Sensors (Switzerland), vol. 14, no. 1, pp. 868–876, 2014.

[40] B. Zhang, K. Kagawa, T. Takasawa, M. W. Seo, K. Yasutomi, and S. Kawahito, "RTS noise and dark current white defects reduction using selective averaging based on a multi-aperture system," Sensors (Switzerland), vol. 14, no. 1, pp. 1528–1543, 2014.

[41] O. García-Beltrán et al., "Coumarin-based fluorescent probes for dual recognition of copper(II) and iron(III) ions and their application in bio-imaging," Sensors (Switzerland), vol. 14, no. 1, pp. 1358–1371, 2014.

[42] S. Meier, P. R. Jensen, M. Karlsson, and M. H. Lerche, "Hyperpolarized NMR probes for biological assays," Sensors (Switzerland), vol. 14, no. 1, pp. 1576–1597, 2014.

[43] A. Hristoskova, V. Sakkalis, G. Zacharioudakis, M. Tsiknakis, and F. De Turck, Ontology-driven monitoring of patient's vital signs enabling personalized medical detection and alert, vol. 14, no. 1. 2014.

[44] F. Ishmanov, S. W. Kim, and S. Y. Nam, "A secure trust establishment scheme for wireless sensor networks," Sensors (Switzerland), vol. 14, no. 1, pp. 1877–1897, 2014.

[45] X. Liang et al., "Possibilities of a personal laser scanning system for forest mapping and ecosystem services," Sensors (Switzerland), vol. 14, no. 1, pp. 1228–1248, 2014.

[46] E. Heinz, P. Kraft, C. Buchen, H. G. Frede, E. Aquino, and L. Breuer, "Set up of an automatic water quality sampling system in irrigation agriculture," Sensors (Switzerland), vol. 14, no. 1, pp. 212–228, 2013.

[47] A. R. Jiménez, F. Zampella, and F. Seco, Improving inertial Pedestrian Dead-Reckoning by detecting unmodified switched-on lamps in buildings, vol. 14, no. 1. 2014.

[48] P. M. Pantau, U. Meningkatkan, K. Menulis, and S. Dalam, "Penerapan metode pantau, pangkas, padukan, panggil (4p) untuk meningkatkan keterampilan menulis siswa dalam meringkas cerita," vol. 2, no. 1, 2017.

[49] S. Mayasari and C. Indraswari, "Efektivitas Media Sosial Instagram Dalam Publikasi HUT Museum Nasional Indonesia ( MNI ) Kepada Masyarakat," vol. 9, no. 2, 2018.

[50] A. N. Yuhana, "Optimalisasi Peran Guru Pendidikan Agama Islam sebagai Konselor dalam Mengatasi Masalah Belajar Siswa," vol. 7, no. 1, 2019.

[51] D. Pilendia, "Pemanfaatan Adobe Flash Sebagai Dasar Pengembangan Bahan Ajar Fisika : Studi Literatur," J. Tunas Pendidik., vol. 2, no. 2, pp. 1–10, 2020.

[52] A. Nuryana, P. Utari, and U. S. Maret, "Pengantar metode penelitian kepada suatu pengertian yang mendalam mengenai konsep fenomenologi," pp. 19–24, 2019.

[53] N. Riani, "Model Perilaku Pencarian Informasi Guna Memenuhi Kebutuhan Informasi ( Studi Literatur )," vol. 1, no. 2, 2017

[54] E. Riana, "Implementasi Cloud Computing Technology dan Dampaknya Terhadap Kelangsungan Bisnis Perusahaan Dengan Menggunakan Metode Agile dan Studi Literatur," vol. 7, no. 3, pp. 439–449, 2020.

[55] P. Pmr and M. Siswa, "Studi literatur meningkatkan kemampuan berpikir kreatif dengan pendekatan pmr matematis siswa," no. December, 2019.

[56] T. Ayu and U. Tarigan, "Prosedur Penerbitan Surat Keputusan Pensiun Pegawai Negeri Sipil pada Badan Kepegawaian Daerah Deli Serdang," vol. 2, no. 1, pp. 18–29, 2014.

[57] W. Oktaviani, "Penerapan Model Pembelajaran Discovery Learning Untuk Meningkatkan Kemampuan Berpikir Kritis Dan Hasil Belajar Matematika Siswa Kelas 5 Sd," J. Basicedu, vol. 2, no. 2, pp. 5–10, 2018.

[58] P. D. A. N. Pengajaran, "Observasi sebagai alat evaluasi dalam dunia pendidikan dan pengajaran," vol. 11, no. 2, pp. 220–233, 2008.

[59] B. C. Neyfa and D. Tamara, "Perancangan Aplikasi E-Canteen Berbasis Android Dengan Menggunakan Metode Object Oriented Analysis & Design ( Ooad )," pp. 83–92, 2016.

[60] E. Leonardo, P. M. Bisnis, P. S. Manajemen, U. K. Petra, and J. Siwalankerto, "Pengaruh Pemberian Kompensasi Terhadap Kinerja Karyawan Pada Pt . Kopanitia," vol. 3, no. 2, pp. 3–6, 2015.

[61] W. B. Sulfemi, "Hubungan motivasi belajar dengan hasil belajar ips di smp kabupaten bogor," vol. 18, no. 106, pp. 1–12.

[62] I. Sappe, P. Guru, S. Dasar, and U. M. Makassar, "Hubungan Motivasi Belajar Terhadap Hasil Belajar Ipa Siswa Kelas V Sdn 231 Inpres Kapunrengan Kecamatan Mangarabombang," vol. 3, 2018.

[63] Y. Zhao, "Interaction Design System for Artificial Intelligence User Interfaces Based on UML Extension Mechanisms," Mob. Inf. Syst., vol. 2022, 2022.

[64] A. Nanthaamornphong and A. Leatongkam, "Extended ForUML for Automatic Generation of UML Sequence Diagrams from Object-Oriented Fortran," Sci. Program., vol. 2019, 2019.

[65] J. M. Bezerra and C. M. Hirata, "A Polyadic pi-Calculus Approach for the Formal Specification of UML-RT," Adv. Softw. Eng., vol. 2009, pp. 1–26, 2009.

[66] S. E. Pon Pushpa and M. Devasigamani, "Utilization bound scheduling analysis for nonpreemptive uniprocessor architecture using UML-RT," Model. Simul. Eng., vol. 2014, 2014.

[67] Z. Zhang, R. Zhang, and Z. Qin, "Composite-Level Conflict Detection in UML Model Versioning," Math. Probl. Eng., vol. 2015, 2015.

[68] S. Bernardi, J. Merseguer, and D. C. Petriu, "Dependability modeling and assessment in UML-based software development," Sci. World J., vol. 2012, 2012.

[69] A. Nanthaamornphong, K. Morris, and S. Filippone, "Extracting UML class diagrams from object-oriented Fortran: ForUML," Proc. SE-HPCCSE 2013 1st Int. Work. SE High Perform. Comput. Comput. Sci. Eng. - Held Conjunction with SC 2013 ICHPC, Networking, Storage Anal., vol. 2015, pp. 9–16, 2013.

[70] A. Magableh, Z. Shukur, and N. Mohd. Ali, "Comprehensive aspectual UML approach to support aspectJ," Sci. World J., vol. 2014, 2014.

[71] A. Nayak and D. Samanta, "Synthesis of Test Scenarios Using UML Sequence Diagrams," ISRN Softw. Eng., vol. 2012, pp. 1–22, 2012.

[72] M. Tabrani and I. Rezqy Aghniya, "Implementasi Metode Waterfall Pada Program Simpan Pinjam Koperasi Subur Jaya Mandiri Subang," J. Interkom J. Publ. Ilm. Bid. Teknol. Inf. dan Komun., vol. 14, no. 1, pp. 44–53, 2020.

# Investigating the Role of Machine Learning Algorithms in Predicting Sepsis using Vital Sign Data

Amit Sundas[1], Sumit Badotra[2], Gurpreet Singh[3], Amit Verma[4],
Salil Bharany[5]*, Imtithal A. Saeed[6], Ashraf Osman Ibrahim[7]*

Department of Computer Science and Engineering, Lovely Professional University, Phagwara, Punjab, India[1, 3, 5]
School of Computer Engineering and Technology, Bennett University, Greater Noida, India[2]
University Centre for Research and Development, Department of Computer Science and Engineering,
Chandigarh University, India[4]
Prince Sattam Bin Abdulaziz University, College of Computer Engineering and Sciences,
Department of Information Systems, Saudi Arabia[6]
Creative Advanced Machine Intelligence Research Centre-Faculty of Computing and Informatics,
Universiti Malaysia Sabah, 88400 Kota Kinabalu, Sabah, Malaysia[7]

*Abstract*—Objective: In hospitals, sepsis is a common and costly condition, but machine learning systems that utilize electronic health records can enhance the timely detection of sepsis. The purpose of this research is to verify the effectiveness of a machine learning tool that makes use of a gradient boosted ensemble for sepsis diagnosis and prediction in relation. San Francisco University of California, (SFUC) Medical Center and the Medical Information Mart for Intensive Care (MIMIC) databases were consulted for historical information. The study encompassed adult patients who were admitted without sepsis and had a minimum single logging of six vital signs (SpO2, temperature, heart rate, respiratory rate, diastolic blood pressure and systolic). Using the area under the receiver operating characteristic (AUROC) curve, the performance of the machine learning algorithm was compared to commonly used scoring systems, and its accuracy was determined. Performance of the MLA (machine learning algorithm) was evaluated at sepsis onset, as well as 24 and 48 hours before sepsis onset. The AUROC for the MLA was 0.88, 0.84, and 0.83 for sepsis onset, 24 hours prior, and 48 hours prior, respectively. At the time of onset, these values were superior to those of SOFA, MEWS, qSOFA, and SIRS. Using UCSF data for training and MIMIC data for testing, the sepsis onset AUROC was 0.89. The MLA can safely predict sepsis up to forty-eight hours before it occurs and the accuracy in detecting the onset of sepsis is higher in comparison to traditional instruments. When trained and evaluated on distinct datasets, the MLA maintains high performance for sepsis detection.

*Keywords—Machine learning; sepsis; vital sign; prediction; electronic health records*

## I. INTRODUCTION

Sepsis, a widespread and economically burdensome syndrome affecting hospitals worldwide, has undergone a transformative shift in its conceptualization. While it was formerly categorized within a three-tier system, the prevailing understanding characterizes it as a two-stage process, spanning from septic conditions to full-blown sepsis. The projected annual cost to the global healthcare system attributed to sepsis is a staggering $24 billion, an alarming financial burden. This is particularly disconcerting when considering the fatality rates associated with sepsis, which range from 25% to 40%. However, emerging evidence underscores the significance of early diagnosis and intervention before the onset of septic shock, as it holds the potential to significantly improve patient outcomes and reduce hospitalization durations [1].

Sepsis, often characterized by organ malfunction due to a systemic inflammatory response to infection, poses a formidable diagnostic challenge due to the intricate and varied origins of infections and the unique responses of individual patients. Consequently, there has been a growing impetus in medical science to advance automated patient monitoring systems tailored for the early identification of sepsis among hospitalized patients [2].

The advent of automated diagnostic decision and prediction technologies, facilitated by the widespread adoption of electronic health records (EHRs) in healthcare facilities, holds substantial promise for revolutionizing the tracking and management of complex medical conditions [3]. These technologies derive their foundations from the comprehensive medical records of patients, utilizing this wealth of data to generate warnings and treatment recommendations [4]. However, it is noteworthy that the existing diagnostic methods for sepsis predominantly lack predictive capabilities [5-7], with the majority relying on rule-based processes to trigger alarms and provide recommendations.

Within clinical settings, the commonly employed sepsis scoring systems encompass the Systemic Inflammatory Response Syndrome (SIRS) criteria [6], the Modified Early Warning Scale (MEWS) [8], and the Sequential Organ Failure Assessment (SOFA) score [9]. While these systems exhibit commendable sensitivity, they often grapple with issues related to specificity and are not explicitly designed for predicting the development of sepsis. Moreover, rule-based scores may struggle to accurately account for the diverse patient populations and the multifaceted sources of infection. Machine learning-based prediction techniques hold the potential to offer superior specificity, broader generalizability, and early sepsis risk identification, thus potentially reducing false alarms and enabling more timely physician responses [12].

Previous research endeavors have revealed the capacity to forecast the onset of sepsis, septic shock, and severe sepsis with a lead time of up to four hours before the condition manifests, employing machine learning-based systems trained on patient EHR data [13-14]. However, these studies were primarily conducted within the confines of a single institution's critical care group. In this study, we align with the contemporary definition of sepsis proposed by Singer et al. [1] to evaluate the historical performance of an algorithm employing a mixed-ward dataset, predicting sepsis up to two days in advance, solely relying on vital sign inputs. Moreover, our research aims to assess the algorithm's effectiveness by benchmarking its performance against prevailing rule-based scoring systems and scrutinizing its reliability through cross-population validation, as elucidated in study [15].

## II. RELATED WORK

In the realm of predicting sepsis using vital sign data, extensive research has been conducted to explore the role of machine learning algorithms. This section provides an overview of existing studies and their contributions, offering insights into the progress made in this critical domain and highlighting the gaps and areas requiring further investigation.

Numerous researchers have delved into the development of sepsis prediction models, aiming to enhance early detection and intervention. Studies by [1-3] and [10-14] have primarily focused on utilizing machine learning algorithms to analyze vital sign data for sepsis prediction. These studies have demonstrated promising results in terms of accuracy and timeliness, providing a foundation for further exploration.

In contrast, [16] and [17] have employed alternative approaches, such as rule-based scoring systems, to predict sepsis. While these methods have proven valuable in clinical settings, they raise questions about the potential advantages of machine learning algorithms in terms of predictive power and adaptability.

While substantial progress has been made in the field of sepsis prediction, there are still various challenges that demand attention. These include addressing the interpretability of machine learning models, optimizing feature selection, and ensuring generalizability across diverse patient populations and healthcare settings. The research presented in this study seeks to contribute to this ongoing discourse by:

- Our unique approach employs a gradient boosted ensemble for sepsis diagnosis, leveraging SFUC and MIMIC electronic health records.

- We include adult patients without sepsis who have recorded six vital signs. We evaluate the algorithm's performance with AUROC and compare it to traditional scoring systems.

- Also in Results, MLA has an AUROC of 0.88 at sepsis onset, 0.84 and 0.83 for predictions 24 and 48 hours earlier. Outperforms SOFA, MEWS, qSOFA, and SIRS. MLA trained on UCSF data, tested on MIMIC, reaches AUROC of 0.89.

- Our research shows MLA may predict sepsis up to 48 hours earlier with high accuracy, contributing to improved early sepsis management.

By reviewing the existing solutions and identifying areas that warrant further exploration, this research aims to position itself within the broader landscape of sepsis prediction, ultimately striving to enhance the effectiveness of early intervention in critical healthcare scenarios.

## III. COMPONENTS

### A. Ethics Certification and Informed Consent

As mandated by the Health Insurance Portability and Accountability Act (HIPAA), we removed all personally identifying information from patient records before collecting the datasets. There was no compromise in patient well-being due to the data gathering procedure [16].

### B. Measurements

Six vital signs (systolic BP, heart rate, temperature, respiration rate, diastolic BP and peripheral oxygen saturation (SpO2)) were examined to establish sepsis risk ratings. To be included in the research, it was required that every patient encounter had a minimum of one record for each vital sign. These are the sole vitals we engage in the act of generating or producing characteristics for assessing sepsis threat scores since they are directly related to sepsis development and are evaluated often even in the absence of a clinical concern for septic shock [17].

### C. Sources Data

The datasets utilised in this study came from the Medical Center at the University of California, San Francisco (SFUC) and the Intensive Care Unit section of the Medical Information Market (MIMIC). Patients who visited the Parnassus Heights, Mission Bay, or Mount Zion facilities between June 2016 and March 2023 accounted for 17,467,987 of the total contacts in the SFUC dataset. Our final group consisted of 91,445 patients after excluding those with hospital stays less than seven hours and more than 2000 hours from the original 96,646 inpatients (95,869 of whom had at least one recording of each vital sign). We employed subsets of this final sample, differentiated by patients' lengths of stay, to conduct our 24- and 48-hour lookahead analyses. Different frequencies of data collection and types of care provided were documented in the SFUC data from the ICU, the ED, and the floor units [18-19]. Due to missing unit transfer timestamps, it was impossible to determine where a patient was located at any given moment. The MIMIC information was culled from the 61,532 ICU interactions recorded in the Medical Information Mart for Intensive Care III (MIMIC-III) v1.3 database between the years of 2012 and 2023. Patients 18 and older had 52,902 visits to the hospital, but only 21,507 had at least one recording of each vital sign, qualifying them for inclusion in the final cohort. Missing measurements of any vital sign were grounds for excluding encounters. Patient safety was not jeopardised by the data collecting process, and all patient information was de-identified in accordance with HIPAA regulations. SFUC's IRB (Institutional Review Board) gave its clearance to this project [20].

## D. Statistical Analysis

We extracted the sensitivity, specificity, and AUROC value with 95% CI for predicting sepsis patients in the ICU from each of the included studies. The ROC curve compares different thresholds by plotting the true positive rate (TPR) against the false positive rate (FPR). Excellent, good, fair, poor, and fail are defined by AUROC curve values of 0.9-1, 0.8-0.9, 0.7-0.8, 0.6-0.7, and 0.5-0.6, respectively. In the end, we calculated the ROC, sensitivity, and specificity with 95% CI. To gauge the degree of statistical heterogeneity among the included trials, we calculated an I² value. Heterogeneity is classified as extremely low (I² ~25%), low (I² ~50%), medium (I² ~75%), or high (I² > 75%), respectively. There was less variation in impact sizes across trials because data from all included research were combined using a random effect model. The proportion of overall study variance that can be attributed to factors other than chance is measured by the I2 statistic [21]. To determine I², we used the formula:

$$I^2 = 100 \% \ (Q - df)/Q \quad (1)$$

Q = dfQ, where df = number of observations and Q = Cochrane's heterogeneity statistic. As a consequence, the I² findings range from 0% (no observed heterogeneity) to 100% (highest heterogeneity), with all negative values adjusted to zero.

We selected the symmetric approach in our meta-analysis because we hypothesized that the included papers would be of varying quality. The pooled estimate of AUROC, sensitivity, specificity, and diagnostic odds ratio was calculated using MetaDiSc (version 1.4). It's useful for doing things like (a) summarizing data from each research, (b) analyzing the graphical and statistical similarity of studies, (c) computing the pooled estimate, and (d) examining heterogeneity. The likelihood ratio was calculated to illustrate the extent to which a given outcome was more common in studies including patients with sepsis illness compared to those involving subjects without sepsis disease.

$$LR+ = (Sensitivity/1 - Specificity) \quad (2)$$

$$LR- = (1 - Sensitivity/Specificity) \quad (3)$$

Additionally, diagnostic odds ratio (DOR) was calculated to reveal how much higher the chances are for persons with a positive test result to have the sepsis illness compared to those with a negative test result. The formula for DOR is LR + /LR-. Each technique's efficacy was measured using a number of different metrics (Supplementary Table 2), including area under the receiver operating curve, sensitivity, specificity, diagnostic odd ratio, and probability ratio.

The precise confidence bounds for the binomial percentage were calculated using the F distribution technique, and the confidence ranges for overall sensitivity and specificity were analyzed as well [19]. However, excess dispersion correction was applied in the computations, and Meta-DiSc was the tool of choice. The typical approximation to binomial was used here.

$$SE \ (SenT) \ = \ \sqrt{\frac{SenT(1 - SenT)}{\sum_i Di}} \quad (4)$$

$$SE \ (Sper) \ = \ \sqrt{\frac{Senr(1 - Senr)}{\sum_i Di}} \quad (5)$$

$$SenT \ \pm \ Z_{\frac{\alpha}{2\varphi Sen}} SE(Senr) \quad (6)$$

$$Sper \ \pm \ Z_{\frac{\alpha}{2\varphi Spe}} SE(Spen) \quad (7)$$

## IV. METHODOLOGIES

### A. Results and Methods

The capability of the algorithm to detect individuals that are septic at start and in the preceding 24 and 48 hours was the primary focus of this study. We evaluated the efficacy of the method by calculating the AUROC, or area under the receiver operating characteristic curve.

The data was collected through queries built for the PostgreSQL (PostgreSQL Global Development Group) database and then saved as CSV files [19]. Features for predicting sepsis risk were created using just six vital signs: heart rate, respiration rate, systolic blood pressure, SpO2, diastolic blood pressure and temperature. If there wasn't a fresh reading for each hour leading up to the patient's designated onset time, the previous reading was used to estimate the value. When several readings were obtained within the same hour, an average was calculated and utilized. This cut down on the classification system's exposure to measurement frequency data that wasn't relevant to physiology [21].

Information was also gathered to create the Sepsis-3 reference standard and the rules-based grading system. Often used measures such as the Sequential Organ Failure Assessment (SOFA), Modified Rankin Scale (MERS), and qSOFA (quick SOFA) were compared to the prediction algorithm. Similar to Jaimes et al. [3], we searched for SIRS criteria. To determine each patient's MEWS score [14], we used the same procedure as Fullerton et al [2]. The formula for calculating a qSOFA score may be found in Singer et al [1]. While the SOFA score is included in the widely accepted definition of sepsis, we investigated its ability to identify the onset of sepsis independently of other factors. CSV files were needed for bilirubin levels, FiO2, PaO2, the Glasgow Coma Scale, white blood cell counts, vasopressor dosages, and platelet counts in order to calculate these scores [22].

Sepsis is "life-threatening organ dysfunction induced by a dysregulated host response to infection," according to the 2016 consensus definition, which served as the basis for the Sepsis-3 gold standard. A 2-point shift in the Sequential Organ Failure Assessment (SOFA) score was considered indicative of organ failure [1]. To determine when the SOFA score shifted, we relied on the criteria established by Seymour et al. [4]. Antibiotics were administered and culture collected within 24 hours or within 72 hours if we suspected there was an infection. Seymour et al. [4] discovered the same thing when they tried testing the approach in reverse. When both the SOFA score and infection requirements were reached for the first time, we diagnosed sepsis [26-27].

There were 2,649 Sepsis-3 positive SFUC encounters out of 91,445 total that were included (a prevalence of 2.9%) in Fig. 1. The Sepsis-3 criteria were satisfied in 1024 out of

21,507 contacts at the MIMIC, yielding a frequency of 4.8%. There was a Sepsis-3 prevalence of 3.3% across all 112,952 patient interactions. The last stage of inclusion criteria for Sepsis-3 eliminated many potentially eligible encounters since the timing of sepsis onset was during the first seven hours of admission [23].



UCSF encounters | BIDMC encounters

17,467,987 | 53,542

Inpatients only

133,578 | 53,002

Patients aged ≥ 18 years

96,646 | 52,902

Patients with ≥ 1 observation for each measurement

95,869 | 23,502

Patients with prediction time between 7 and 2000 hours

91,445 | 21,507

*To Classifier*
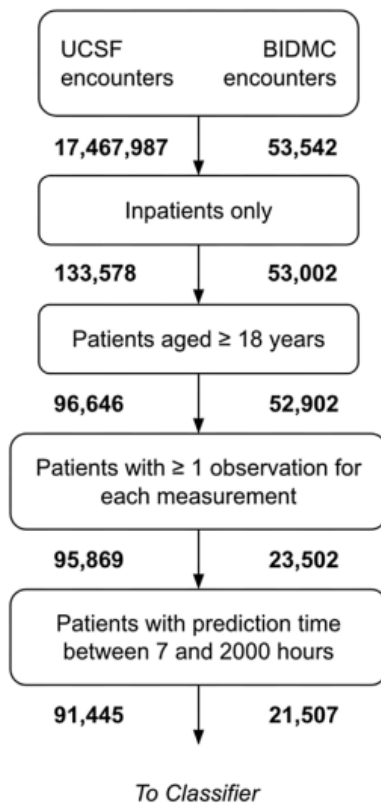
Fig. 1. Graphic illustrating patient inclusion and duration-based subsets in SFUC/MIMIC datasets for training and testing.

The "onset time" for individuals who never acquired sepsis was chosen at random from a continuous, uniform probability distribution so that they might serve as negative examples. The algorithm's risk ratings were derived from data collected both at and before the patient's start time. Patients who were diagnosed with sepsis either at the time of admission or within seven hours of admission were removed from the analysis to make room for prediction windows [24].

Patient contacts were first categorized by duration of stay before training the classifier. Example: a patient who had been hospitalized for 25 hours before contracting sepsis would be included in a 24-hour prediction experiment but not a 48-hour prediction trial. There were 107 cases of Sepsis-3 among the 20,590 MIMIC interactions and 267 cases among the 89,000 SFUC encounters with at least 24 hours of stay data. After at least 48 hours in the hospital, Sepsis-3 was identified in 50 of the 20,533 MIMIC interactions and 97 of the 88,887 SFUC encounters. To keep the calculation matrices manageable, hospital encounters with onset times more than 2000 hours were omitted [25].

## B. The Algorithm for Prediction in Machine Learning

An ensemble of trees was used to generate scores for use in the algorithm's classifier, which was then used to get an overall score [28]. The system utilised one-hour, two-hour, and pre-prediction vital indicators, as well as the hourly changes between them, to make its predictions. A feature vector x containing 30 components, with five values derived from each of the six measurement sources was formed by summing these numbers in a causal fashion. The trees were built using the Python XGBoost module, with each branch being divided into two feature groups [29]. We used a five-fold cross-validation grid search on the training set to determine that a maximum of four, three, and six branches should be used for 0-hour, 24-hour, and 48-hour predictions, respectively [30]. Based on this grid search, we settled on the values 0.05, 0.12, and 0.12 for the XGBoost learning rate parameter. As we employed early stopping to avoid model overfit, we did not need to restrict the maximum number of trees in each ensemble. These risk ratings were then utilised by the algorithm to classify patients as having sepsis or at risk for developing it [31-33].

Two sets of SFUC interactions were created. The first group, made up of 80% of all interactions, was arbitrarily divided into a test set and a training set. Twenty percent of the second set was put aside as a control group for further examination. Using just the training data, we conducted a five-fold cross-validation to find the optimal hyperparameters for the grid search. For this prediction job, we looked into a parameter space that was similar to that of previously described hyperparameters [34-36]. We looked at learning rates between 0.05 and 0.12, in 0.01 increments, and explored numbers between 3 and 8 for the maximum number of branchings. For each look ahead, we settled on the optimal combination of branching level and learning rate based on the average area under the receiver operating characteristic (AUROC) curve [37]. For ten-fold cross-validation, we randomly distributed encounters over ten groups of similar size, each containing 20% of the training set. Nine of these groups were used for training the algorithm for each fold, while the other was used for testing. Each of the ten potential permutations of training and test sets was put through the algorithm and put to the test on the independent test set [38]. We produced machine learning algorithm performance measures by averaging the metrics from ten cross-validation models, including tabular and graphical representations of the findings. In addition, the averaged feature significance scores from XGBoost were presented; these values show how often a feature was utilised to partition the data across the trees. In addition, we calculated the AUROC standard deviation using the cross-validation outcomes [39].

Patient encounter cohorts utilised for 24- and 48-hour prediction were limited to those with sufficient stay data, as previously indicated [40]. As a consequence, there is an inequity in the distribution of socioeconomic classes since fewer septic patients were seen in these cohorts. We took use of XGBoost's built-in capacity to deal with unbalanced classes [40] rather than using minority oversampling to artificially inflate the number of septic patients, which may not be typical of the real-world situation in which such an MLA is implemented.

## C. Methods for Validation in Cross Populations

Cross-population validation studies were undertaken to evaluate the algorithm's sepsis detection ability after being trained on a data set from an individual institution and then evaluated on another with demographic and clinical disparities. We evaluated the algorithm on MIMIC patient measurements after training it on SFUC data but before retraining it on the target dataset. The whole dataset was put through its paces during testing, and the algorithm was trained and validated in the same manner as detailed above. Only at the outset was testing done so that it could be compared to rule-based approaches.
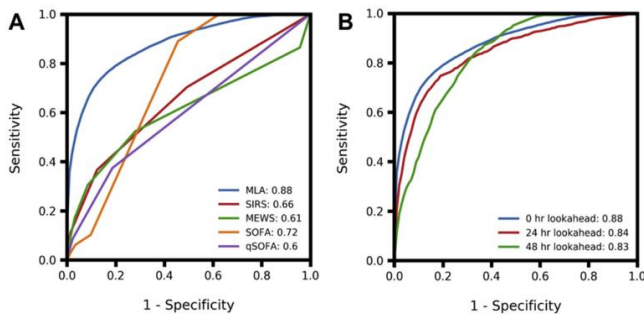


Fig. 2. MLA's efficiency in the hours before onset, and in comparison, to that of rival methods. A) Comparing ROC and AUROC of MLA to rival scoring systems at sepsis onset using SFUC data. B) ROC and AUROC for MLA at 0, 24, and 48 hours prior to sepsis onset using SFUC patient data.

## V. RESULTS

The research involved analyzing 91,445 patient interactions from SFUC and 21,507 patient encounters from MIMIC based on the collected data. Demographic characteristics of the two patient groups are compared in Table I, revealing significant differences in various aspects such as healthcare units visited, sepsis rates, in-hospital mortality, and age distributions. Importantly, the MIMIC database exclusively included ICU admissions, while the SFUC dataset encompassed all inpatient contacts. This deliberate selection of disparate data sets was aimed at evaluating the potential generalizability of the prediction system across a diverse range of patient groups.

In contrast to the qSOFA (0.60), MEWS (0.61), SIRS (0.66), and SOFA (0.72) scoring systems applied to the same dataset, the machine learning method developed and evaluated on the SFUC dataset exhibited a superior AUROC (0.88) for sepsis prediction (see Fig. 2). Additional performance indicators are detailed in Table II. Notably, the false alarm rates generated by the MLA, SIRS, and SOFA models were 0.22, 0.49, and 0.41, respectively, at specified operating points. It is significant to note that SIRS and SOFA generated 2.22 and 1.86 times as many false warnings as the MLA, respectively.

Furthermore, the study evaluated the algorithm's performance in predicting sepsis 24 and 48 hours before its onset, achieving AUROC values of 0.84 and 0.83, respectively (see Fig. 2 and Table II). During the 24-hour prediction, a dataset of 89,000 SFUC patients was analyzed, including 267 septic cases, and for the 48-hour prediction, a dataset of 88,887 SFUC patients was analyzed, including 97 septic cases. Notably, both predictions yielded higher diagnostic odds ratios (DOR) than initially predicted by rules-based approaches (see Table II).

Additionally, the study included data from MIMIC, which comprised 21,507 patients and 1024 septic cases. Remarkably, the algorithm, trained on the SFUC database without retraining, achieved an AUROC of 0.890 when applied to the MIMIC dataset.

The critical question arising from these results pertains to whether the MLA method can generate similar results when applied to infections other than sepsis. It prompts further consideration regarding whether the methodology's applicability is confined exclusively to sepsis or if it can be generalized to other medical contexts.

TABLE I.        COHORT DEMOGRAPHICS BETWEEN SFUC AND MIMIC

| Summary of the Population | Characteristic | MIMIC (%) | SFUC (%) |
|---|---|---|---|
| Gender | Male | 56.13 | 45.38 |
|  | Female | 43.87 | 54.62 |
| Ages[1] | 70+ | 40.26 | 20.44 |
|  | 60–69 | 22.79 | 21.22 |
|  | 50–59 | 17.89 | 18.62 |
|  | 40–49 | 9.73 | 13.02 |
|  | 30–39 | 4.99 | 15.20 |
|  | 18–29 | 4.34 | 11.50 |
| Length of Stay (days)[2] | 9+ | 10.05 | 17.02 |
|  | 6–8 | 8.24 | 14.21 |
|  | 3–5 | 32.38 | 38.42 |
|  | 0–2 | 49.34 | 30.35 |
| Death During Hospital Stay | No | 72.92 | 97.81 |
|  | Yes | 27.08 | 2.19 |
| ICD-9 Code | Septic Shock | 7.00 | 1.85 |
|  | Severe Sepsis | 10.19 | 3.69 |
|  | Sepsis | 3.48 | 5.83 |

Note - 91,445 patients make up the SFUC cohort. There are 21,507 patients in the MIMIC cohort.

1. Median age at SFUC was 55 (interquartile range [IQR]: 38-67), whereas at MIMIC it was 65 (IQR: (53, 77).

2. Median (SFUC): 4 (interquartile range [IQR]: (2, 6.32); median (MIMIC): 3 (2, 4)

Every one of the prediction windows was given a feature significance value (Supplementary Table I). The five most highly rated characteristics are shown in Table II. Age was the single most influential factor across all prediction intervals. After taking into account age, the greatest total score came from taking the patient's temperature, systolic blood pressure and heart rate simultaneously.

TABLE II.    PRE-SEPSIS MLA PERFORMANCE ASSESSMENTS AND COMPARISON SCORES DURING THE START OF SEPSIS

|  | MLA (t = −48) | MLA (t = −24) | MLA (t = 0) | MEWS (t = 0) | SIRS (t = 0) | SOFA (t = 0) | qSOFA[1] (t = 0) |
|---|---|---|---|---|---|---|---|
| **AUROC (SD)** | 0.83 (0.04) | 0.84 (0.04) | 0.88 (0.008) | 0.61 | 0.66 | 0.72 | 0.60 |
| **LR+** | 2.86 | 2.57 | 3.76 | 1.86 | 1.43 | 1.92 | 2.00 |
| **Sensitivity** | 0.84 | 0.80 | 0.80 | 0.52 | 0.70 | 0.78 | 0.37 |
| **LR-** | 0.21 | 0.28 | 0.26 | 0.66 | 0.56 | 0.37 | 0.77 |
| **Specificity** | 0.66 | 0.72 | 0.78 | 0.72 | 0.51 | 0.59 | 0.81 |
| **DOR** | 13.15 | 13.69 | 14.79 | 2.81 | 2.44 | 5.20 | 2.60 |

**Note**. On the basis of patient data from SFUC, we evaluate MLA performance at 0, 24, and 48 hours before commencement, as well as competing scores at the time of onset. The setpoints were selected with sensitivities around 0.80 in mind. Just the MLA's cross-validation standard deviation in AUROC was computed.

[a.] **Abbreviation**. SD, standard deviation; LR+, positive likelihood ratio; LR-, negative likelihood ratio.

[1] All settings for qSOFA generated sensitivities much outside of the 0.80 range.

## VI. CONCLUSION

The machine learning system evaluated in this research has the potential to revolutionize the way sepsis is diagnosed and treated. With an impressive AUROC of 0.83, the system has shown a high degree of accuracy in predicting sepsis up to 48 hours before the onset of symptoms. This early warning capability is crucial in ensuring that patients receive timely and appropriate treatment, leading to improved health outcomes.

Future work could focus on the implementation of the algorithm in clinical practice to assess its practical utility and to validate its performance across multiple healthcare systems. Additionally, further exploration could be done to identify additional predictive variables that may enhance the algorithm's performance, as well as potential applications of the algorithm for other clinical conditions. Overall, the potential for machine learning algorithms to improve sepsis detection and patient outcomes warrants further investigation and development in the field of healthcare.

## REFERENCES

[1] M. Singer, C.S. Deutschman, C.W. Seymour, M. Shankar-Hari, D. Annane, M. Bauer, et al., The third international consensus definitions for sepsis and septic shock (Sepsis-3), J. Am. Med. Assoc. 315 (8) (2016) 801–810, https://doi.org/10.1001/jama.2016.0287.

[2] J.N. Fullerton, C.L. Price, N.E. Silvey, S.J. Brace, G.D. Perkins, Is the Modified Early Warning Score (MEWS) superior to clinician judgement in detecting critical illness in the pre-hospital environment? Resuscitation 83 (2012) 557–562.

[3] F. Jaimes, J. Garcés, J. Cuervo, F. Ramirez, J. Ramirez, A. Vargas, et al. The systemic inflammatory response syndrome (SIRS) to identify infected patients in the emergency room, Intensive Care Med. 29 (2003) 1368–1371, https://doi.org/10.1007/s00134-003-1874-0.

[4] C.W. Seymour, V.X. Liu, T.J. Iwashyna, F.M. Brunkhorst, T.D. Rea, A. Scherag, et al., Assessment of clinical criteria for sepsis: for the third international consensus definitions for sepsis and septic shock (Sepsis-3), J. Am. Med. Assoc. 315 (8) (2016 Feb 23) 762–774.

[5] Sundas, A., & Panda, S. (2019). Iot and wsn based smart surveillance system for patients with closed-loop alarm. International Journal of Scientific & Technology Research, 8, 508-511.

[6] Nashif, S., Raihan, M. R., Islam, M. R., & Imam, M. H. (2018). Heart disease detection by using machine learning algorithms and a real-time cardiovascular health monitoring system. World Journal of Engineering and Technology, 6(4), 854-873.

[7] Luo, J., Lan, L., Huang, S., Zeng, X., Xiang, Q., Li, M., ... & Zhou, X. (2023). Real-time prediction of organ failures in patients with acute pancreatitis using longitudinal irregular data. Journal of Biomedical Informatics, 139, 104310.

[8] Sundas, A., Badotra, S., Rani, S., & Gyaang, R. (2023). Evaluation of Autism Spectrum Disorder Based on the Healthcare by Using Artificial Intelligence Strategies. Journal of Sensors, 2023.

[9] Dahan, F., Alroobaea, R., Alghamdi, W., Mohammed, M. K., Hajjej, F., & Raahemifar, K. (2023). A smart IoMT based architecture for E-healthcare patient monitoring system using artificial intelligence algorithms. Frontiers in Physiology, 14, 40.

[10] Forkan, A. R. M., Khalil, I., & Atiquzzaman, M. (2017). ViSiBiD: A learning model for early discovery and real-time prediction of severe clinical events using vital signs as big data. Computer Networks, 113, 244-257.

[11] Alfian, G., Syafrudin, M., Ijaz, M. F., Syaekhoni, M. A., Fitriyani, N. L., & Rhee, J. (2018). A personalized healthcare monitoring system for diabetic patients by utilizing BLE-based sensors and real-time data processing. Sensors, 18(7), 2183.

[12] Alghatani, K., Ammar, N., Rezgui, A., & Shaban-Nejad, A. (2021). Predicting intensive care unit length of stay and mortality using patient vital signs: machine learning model development and validation. JMIR medical informatics, 9(5), e21347.

[13] Sundas, A., Badotra, S., Bharany, S., Almogren, A., Tag-ElDin, E. M., & Rehman, A. U. (2022). HealthGuard: An Intelligent Healthcare System Security Framework Based on Machine Learning. Sustainability, 14(19), 11934.

[14] da Silva, D. B., Schmidt, D., da Costa, C. A., da Rosa Righi, R., & Eskofier, B. (2021). DeepSigns: A predictive model based on Deep Learning for the early detection of patient health deterioration. Expert Systems with Applications, 165, 113905.

[15] Kim, S. Y., Kim, S., Cho, J., Kim, Y. S., Sol, I. S., Sung, Y., ... & Sohn, M. H. (2019). A deep learning model for real-time mortality prediction in critically ill children. Critical care, 23(1), 1-10.

[16] Ahmed, U., Lin, J. C. W., & Srivastava, G. (2023). Multivariate time-series sensor vital sign forecasting of cardiovascular and chronic respiratory diseases. Sustainable Computing: Informatics and Systems, 100868.

[17] Peng, H. T., Siddiqui, M. M., Rhind, S. G., Zhang, J., Teodoro da Luz, L., & Beckett, A. (2023). Artificial intelligence and machine learning for hemorrhagic trauma care. Military Medical Research, 10(1), 1-20.

[18] Staszak, K., Tylkowski, B., & Staszak, M. (2023). From Data to Diagnosis: How Machine Learning Is Changing Heart Health Monitoring. International Journal of Environmental Research and Public Health, 20(5), 4605.

[19] Sundas, A., & Badotra, S. (2022, October). Recurring Threats to Smart Healthcare Systems Based on Machine Learning. In 2022 10th International Conference on Reliability, Infocom Technologies and Optimization (Trends and Future Directions)(ICRITO) (pp. 1-8). IEEE.

[20] Elhaj, H., Achour, N., Tania, M. H., & Aciksari, K. (2023). A comparative study of supervised machine learning approaches to predict patient triage outcomes in hospital emergency departments. Array, 17, 100281.

[21] Zhang, H., Wang, L. C., Chaudhuri, S., Pickering, A., Usvyat, L., Larkin, J., ... & Kotanko, P. (2023). Real-time prediction of intradialytic

hypotension using machine learning and cloud computing infrastructure. Nephrology Dialysis Transplantation, gfad070.

[22] Gupta, S., Shabaz, M., Gupta, A., Alqahtani, A., Alsubai, S., & Ofori, I. (2023). Personal HealthCare of Things: A novel paradigm and futuristic approach. CAAI Transactions on Intelligence Technology.

[23] Manjula, S., Vanitha, R., & Geetha, K. Prediction of Health Conditions Of Patient Using Iot Based Machine Learning.

[24] Im, J. E., Yoon, S. A., Shin, Y. M., & Park, S. (2023). Real-Time Prediction for Neonatal Endotracheal Intubation Using Multimodal Transformer Network. IEEE Journal of Biomedical and Health Informatics.

[25] Sundas, A., Badotra, S., & Singh, G. (2023, January). Sensor Data Transforming into Real-Time Healthcare Evaluation: A Review of Internet of Things Healthcare Monitoring Applications. In 2023 International Conference on Intelligent and Innovative Technologies in Computing, Electrical and Electronics (IITCEE) (pp. 559-567). IEEE.

[26] Churpek MM, Yuen TC, Winslow C, et al. Multicenter development and validation of a risk stratification tool for ward patients. Am J Respir Crit Care Med 2014; 190(6): 649–655.

[27] Churpek MM, Yuen TC, Winslow C, et al. Multicenter comparison of machine learning methods and conventional regression for predicting clinical deterioration on the wards. Crit Care Med 2016; 44(2):368–374.

[28] Knaus WA, Wagner DP, Draper EA, et al. The APACHE III prognostic system. Chest 1991; 100(6):1619–1636.

[29] Subbe CP, Slater A, Menon D, et al. Validation of physiological scoring systems in the accident and emergency department. Emerg Med J 2006; 23(11): 841–845.

[30] Ferreira FL. Serial evaluation of the SOFA score to predict outcome in critically ill patients. JAMA 2001;286(14): 1754–1758.

[31] Marafino BJ, Park M, Davies JM, et al. Validation of prediction models for critical care outcomes using natural language processing of electronic health record data. JAMA Netw Open 2018; 1(8):e185097.

[32] Siontis GCM. Predicting death: an empirical evaluation of predictive tools for mortality. Arch Intern Med 2011; 171(19): 1721–1726.

[33] Mao Q, Jay M, Hoffman JL, et al. Multicentre validation of a sepsis prediction algorithm using only vital sign data in the emergency department, general ward and ICU. BMJ Open 2018; 8(1): e017833.

[34] Lehman L-WH, Adams RP, Mayaud L, et al. A physiological time series dynamics-based approach to patient monitoring and outcome prediction. IEEE J Biomed Health 2015; 19(3): 1068–1076.

[35] Johnson AE, Pollard TJ, Mark RG, et al. Reproducibility in critical care: a mortality prediction case study. In: Proceedings of the 2nd machine learning for healthcare conference (vol. 68), Boston, MA, 18–19 August 2017.

[36] Song, W., Jung, S. Y., Baek, H., Choi, C. W., Jung, Y. H., & Yoo, S. (2020). A predictive model based on machine learning for the early detection of late-onset neonatal sepsis: development and observational study. JMIR medical informatics, 8(7), e15965.

[37] Cheng, C. Y., Kung, C. T., Chen, F. C., Chiu, I. M., Lin, C. H. R., Chu, C. C., ... & Su, C. M. (2022). Machine learning models for predicting in-hospital mortality in patient with sepsis: Analysis of vital sign dynamics. Frontiers in Medicine, 9, 964667.

[38] Moor, M., Rieck, B., Horn, M., Jutzeler, C. R., & Borgwardt, K. (2021). Early prediction of sepsis in the ICU using machine learning: a systematic review. Frontiers in medicine, 8, 607952.

[39] Zhao, Y., Jia, L., Jia, R., Han, H., Feng, C., Li, X., ... & Li, T. (2022). A new time-window prediction model for traumatic hemorrhagic shock based on interpretable machine learning. Shock (Augusta, Ga.), 57(1), 48.

[40] Wardi, G., Carlile, M., Holder, A., Shashikumar, S., Hayden, S. R., & Nemati, S. (2021). Predicting progression to septic shock in the emergency department using an externally generalizable machine-learning algorithm. Annals of emergency medicine, 77(4), 395-406.

# A Novel and Efficient Point Cloud Registration by using Coarse-to-Fine Strategy Integrating PointNet

Chunxiang Liu[1], Tianqi Cheng[2], Muhammad Tahir[3*], Mingchu Li[4], Zhouqi Liu[5], Lei Wang[6*]

School of Resources and Environmental Engineering, Shandong University of Technology, Zibo, Shandong, China[1]
School of Computer Science and Technology, Shandong University of Technology, Zibo, Shandong, China[2,5,6]
School of Software Technology, Dalian University of Technology (DUT), Dalian, 116621, China[3,4]
School of Software Technology, Key Laboratory for Ubiquitous Network and Service Software of Liaoning Province,
Dalian University of Technology (DUT), Dalian, 116650, China[3, 4]

*Abstract*—The registration of the point cloud plays a critical and fundamental role in the computer vision domain. Although quite good registration results have been obtained by using the global, local, and learning-based registration strategies, there are still many problems to solve. For example, the local methods that are based on geometric features are very sensitive to attitude deviation, the global shapes-based methods are easy to result in inconsistency when the distribution differences are obvious and the learning-based registration methods have highly relied on the huge label data. A novel and effective registration method for the point cloud data integrating the coarse-to-fine strategy and the improved PointNet network is proposed to overcome the above-mentioned drawbacks and improve registration accuracy. The improved Random Sample Consensus (RANSAC) algorithm is developed to effectively deal with the initial attitude deviation problem in the coarse registration procedure and the improved Lucas and Kanade (LK) algorithm is proposed based on the classical PointNet framework to reduce the errors of the refine registration, and the whole registration procedure is implemented under a trainable recurrent deep learning architecture. Compared with the state-of-the-art point cloud registration methods, experimental results fully prove that the proposed method can effectively handle the significant attitude deviation and partial overlap problem and achieves stronger robustness and higher accuracy.

*Keywords*—*Point cloud registration; PointNet; coarse-fine registration; random sample consensus (RANSAC) algorithm; Lucas and Kanade (LK) algorithm*

## I. INTRODUCTION

As one of the most faithful and convenient data formats, the datasets of point clouds have been popularly applied in the domain of 3D reconstruction [1, 2], virtual reality [3], augmented reality [4], etc. Due to environmental and other influence factors, the registration of point cloud is an essential step before various tasks of computer vision and robotics applications. For example, in the auto-drive domain, the auto-drive system unifies the point clouds collected from different positions by the laser radar to the same coordinate system to build the three-dimensional high-precision map, and then it matches the real-time collected data to the high-precision map through the point cloud registration [5]. Other typical examples include the three-dimensional location for robotics [6] and the pose estimation from different point cloud data [7].

From a mathematical perspective, the registration procedure of the point cloud is usually treated to be an optimization problem, which searches the space correspondence parameters by minimizing the transformation estimation error under some objective metrics [8]. Once the best correspondences are found, the search stops. Many typical work has been reported in this domain. As a typical example, the famous Iterative Closest Point (ICP) registration firstly iteratively assigns the point to the nearest point in a different space of point cloud and then calculates the least squares distances of point pairs to be the objective function. Because only spatial coordinates are used to guide the search, the ICP is very easy to initialize. However, the traditional ICP algorithm usually requires a large overlap area between two frames of the point clouds [9]. In addition, the robustness is not good enough since only the point features are used but the other important features information is lost. Therefore, some registration methods based on the extracted structural features are proposed to improve the registration accuracy, such as the histograms and adjacent points [10], the Euclidean distance [11], the normal vector difference [12], and the surface curvature [13]. Another classical registration scheme based on the Random Sample Consensus (RANSAC) has been also popularly applied in coarse registration. Among them, the 4-Point Congruent Sets (4PCS) is the respective one, which determines the correspondence by comparing the intersection diagonal ratios of four-point sets [14]. The 4PCS algorithm can handle point cloud registration tasks in complex scenes, and a series of improved versions have been developed. For example, to deal with the registration task in the large-scale scene, the computational complexity can be reduced from $O(n^2)$ to $O(n)$ by the Super 4PCS [15], which uses the intelligent strategy to index; the k-4PCS algorithm [16] improves the registration precision by replacing the randomly sampled points with the sparse key points; the Generalized 4PCS [14] effectively reduce the time cost by no longer strictly restricting the coexistence of four points of the 4PCS in a plane; the V4PCS [17] algorithm incorporates the concept of volume consistency to reduce the time cost and the 2PNS [18] is proposed to deal with the registration problem under the smaller overlapping scenes (with a minimum of only 5% overlap). All of these methods produce good registration results but the deep features have not been carefully considered.

Very recently, with the breakthrough of the theory of deep learning, the learning-based registration methods become the

research spots in this domain. Charles et al. constructs the famous PointNet network [19], in which each point through maximum pooling can extract features without conversion, and it solves the problems of permutation invariance and disorder of the point cloud. Inspired by this work, many deep learning-based registration models have been constructed [20-23]. For example, Wang et al. proposed the DCP algorithm based on the dynamic graph convolution network [24, 25]. It combines the local context information and the communication by using the attention mechanism [26] to get the soft mapping relationship between the point clouds. The registration matrixes (including the translation and rotation) are computed according to both of the smooth mapping relationship and differentiable decomposition of the singular values. The performance of the time efficiency and accuracy is good but it is very sensitive to rigid transformations since it heavily relies on the local geometric features. Therefore, its performance is not satisfying when handling significant initial attitude differences [27]. Zi et al. proposed the feature extraction network RPM-Net [28] to reduce the initialization sensitivity. It calculates the mixed features from the spatial location and the geometric characteristics, and then obtains the soft assignment by using the Sinkhorn layer [29]. Zan et al. constructs a deep learning architecture named "3DSmoothNet" to implement the 3D point cloud registration, and its convolutional layers is represented by using the smoothed density value [30]. Huang et al. proposes the fast registration framework that based on the feature-metric strategy, which considers the registration procedure to minimize the error of the feature-metric projection without correspondences. As reported, it is a semi-supervised model and is very robust to the density difference in point cloud data [31]. For all of these methods, the global shape information can be well used to maintain the robustness, however, the registration results are still not good enough when faced with the distribution differences of the point cloud that caused by the partial overlap.

To overcome the above-mentioned drawbacks and improve registration accuracy, an effective and novel point cloud registration framework based on the improved PointNet network is constructed. To deal with the high sensitivity of the initial attitude differences and the partial overlap, the coarse-to-fine registration strategy is developed. The improved RANSAC algorithm is employed as the coarse-grained registration to reduce the attitude difference and make the input point cloud roughly aligned. The LK alignment method is further improved to enhance the inaccurate alignment caused by the distribution differences and partial overlap. Unlike the classical ICP method or the improved version, the proposed method does not require expensive point-to-point calculations. In addition, due to the excellent learning and extracting ability of deep features, it has better generalization for invisible objects and shape changes.

In summary, the major contributions of this research work are described as follows:

- Firstly, a novel registration framework based on the coarse-to-fine strategy is developed. The coarse registration is used to obtain an excellent initial transformation position and the fine-grained registration is used to implement the further optimization to improve the accuracy. For the coarse registration, the improved RANSAC algorithm is proposed to effectively overcome the default that caused by the initial attitude difference.

- Secondly, the Lucas and Kanade (LK) algorithm is improved to avoid the inherent defect that the feature representations that directly extract from the PointNet cannot adapt to compute the gradient estimation in convolution steps so that it can be used to deal with the small registration errors that caused by the partial overlap.

- Finally, this study is based on the two above improved algorithms, the registration procedure and the coarse-to-fine strategy are carefully implemented under the deep learning architecture of PointNet, and four state-of-the-art registration methods are employed to improve the accuracy and superiority.

This work is divided into four parts. Section 1 introduces some background of the point cloud registration. Section 2 presents all the details of the proposed method. Section 3 tests the method and makes a careful discussion. Section 4 summarizes the conclusions and provides the future plan.

## II. THE WHOLE METHOD

The PointNet provides a learnable structured representation and is usually applied for tasks of point cloud classification and segmentation. To successfully makes it applicable to point cloud registration, the RANSAC algorithm and the LK algorithm to are improved to adapt to the "imaging function" of traditional PointNet and expand the PointNet model, the RANSAC algorithm, and the LK algorithm into a unified deep learning framework, whose structure is shown in Fig. 1.

The proposed registration framework starts from constructing feature representations that from the PointNet. The representations using the global features are input into the improved RANSAC algorithm to compute the rough transformation between different point clouds and the improved LK algorithm refines the roughly transformed results according to the local feature representations. The registration procedure stops until the optimal transformation is found by the recurrent learning.

### A. The MLP Symmetric Pooling Feature Extractor

Let $Q$ and $P$ be the source and target dataset, respectively. $\phi: \square^{3 \times N} \to \square^{K}$, for the inputting point cloud $P \in \square^{3 \times N}$, $Q \in \square^{3 \times N}$, $\phi(P)$ and $\phi(Q)$ generate a eigenvector descriptor of K-dimension, which represents the PointNet function. When the function $\phi$ is applied by the multi-layer perceptron (MLP) to the 3D points in $P$ and $Q$, the dimension of the output is also $K$. Then, the pooling function with symmetry is applied to promote the invariance of point order arrangement, and a K-dimensional global feature descriptor is obtained. The whole structure is shown in Fig. 2.
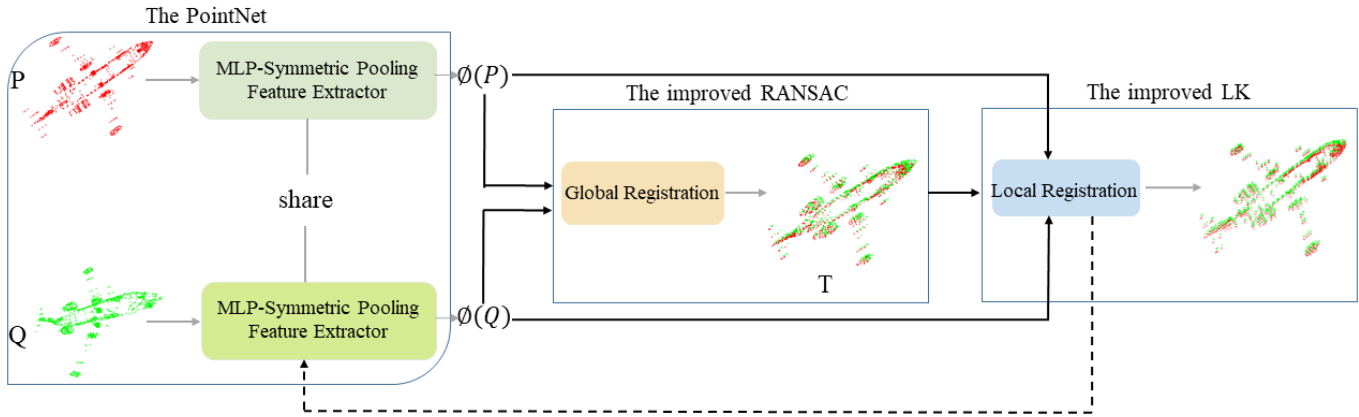
Fig. 1.    The structure of the registration framework.

### B. The Improved RANSAC Algorithm

The advantage of the traditional RANSAC algorithm is that it can automatically match the model according to the data, but it is not effective to compute the corresponding locations of the point cloud. To effectively apply it to 3D point cloud registration, an improved RANSAC algorithm is proposed to calculate the initial registration matrix to minimize the objective functions between the corresponding point cloud. The whole procedure is shown in Fig. 2.
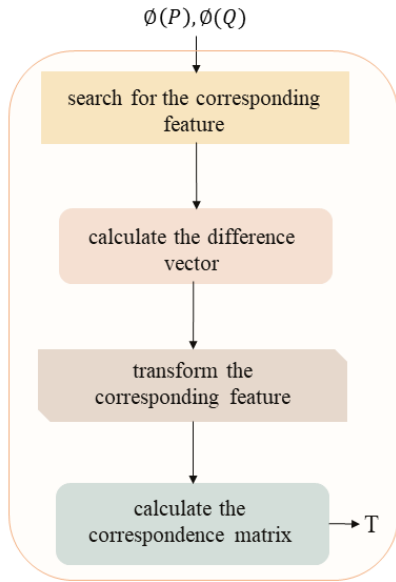


Fig. 2.    The flowchart of the improved RANSAC algorithm.

As shown in Fig. 3, the input of the improved algorithm can be treated to be the K-dimensional feature descriptor corresponding to the two inputting point cloud datasets. The main steps are described as follows:

*1) Search* the corresponding features. Randomly select n features $\{\phi(Q_1), \phi(Q_2), \cdots, \phi(Q_n)\}$, and find the corresponding features $\{\phi(P_1), \phi(P_2), \cdots, \phi(P_n)\}$ in $\phi(P)$ through the nearest neighborhood.

*2) Calculate* the difference vector of the corresponding features. Firstly, the Euclidean distance between the features is calculated; then, the difference ratio is calculated to form the vector $\vec{\eta}$, which is shown in Eq. (1).

$$\vec{\eta} = \left[ \frac{d_{12}^{\phi(P)} - d_{12}^{\phi(Q)}}{\max(d_{12}^{\phi(P)}, d_{12}^{\phi(Q)})}, \frac{d_{23}^{\phi(P)} - d_{23}^{\phi(Q)}}{\max(d_{23}^{\phi(P)}, d_{23}^{\phi(Q)})}, \frac{d_{13}^{\phi(P)} - d_{13}^{\phi(Q)}}{\max(d_{13}^{\phi(P)}, d_{13}^{\phi(Q)})} \right] \quad (1)$$

*3) Correspond* the feature transformation. A temporary transformation matrix $T_i$ is estimated from the corresponding feature pairs, and $\phi(P)$ is converted to $\phi(P_i)$.

*4) Compute* the transformed matrix shown by Eq. (2).

$$T = \arg\min_T g(T) = \arg\min_T \sum_{p \in P} (Tp - q)^2 \quad (2)$$
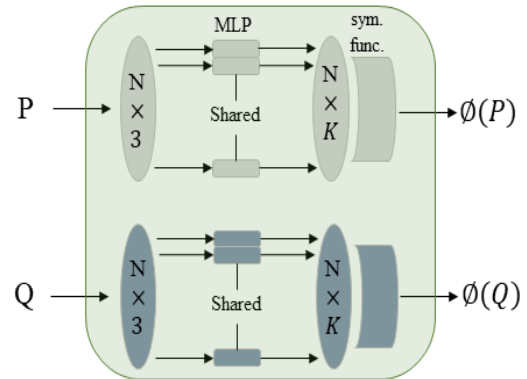


Fig. 3.    The structure of the feature extractor.

### C. The Improved LK Algorithm

In the refine registration, it wants to find the transformation $G$ that best aligns the data $Q$ from $P$, which can be denoted by using the exponential map in Eq. (3).

$$G = \exp(\sum_i \xi_i T_i) \quad (3)$$

where, $\xi = (\xi_1, \xi_2, \cdots, \xi_6)^T$ is the torsion parameter. $T_i$ is the transformation matrix generated by the coarse registration. The three-dimensional point cloud alignment problem can be described as $\phi(P) = \phi(G \cdot Q)$ to find the optimal $G$, where the abbreviation $(\cdot)$ represents the transformation of $Q$ through the rigid transformation $G$.

In the traditional LK algorithm, as shown in Equation (4), the Jacobian matrix is defined to be:

$$J = \frac{\partial}{\partial \xi} \left[ \phi(G^{-1} \cdot P) \right] \tag{4}$$

where $J \in \Box^{K \times 6}$.

Usually, the calculation of the $J$ is not an easy issue for it heavily requires the gradient of the distortion parameter for the PointNet function that relative to $G$. Therefore, as shown in Fig. 4, the stochastic gradient method similar in reference [23] is employed to calculate the value of the Jacobian matrix $J$. Specifically speaking, each column of the Jacobian matrix are approximated by calculating the finite difference gradient that described by the Eq. (5).

$$J_i = \frac{\phi(\exp(-t_i T_i) \cdot P) - \phi(P)}{t_i} \tag{5}$$

where $t_i$ is the infinitesimal perturbation of the torsion parameter $\xi$.
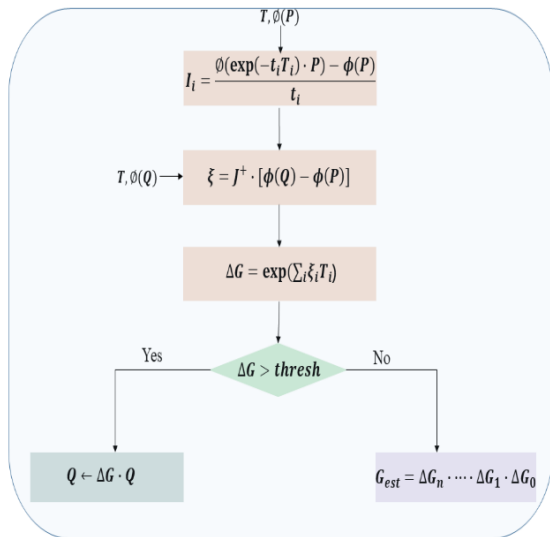


Fig. 4. The flowchart of the improved LK algorithm.

In the improved version, $J$ is equal to an analytic derivative because the *i-th* torsion parameter $t_i$ in each column is non-zero. According to the experiments, a small, fixed value for $t_i$ will produce the better results. The $\xi$ can be expressed as:

$$\xi = J^+ \left[ \phi(Q) - \phi(P) \right] \tag{6}$$

where $J^+$ represents the Moore-Penrose of $J$.

The Equation (6) is used to calculate the optimal twist parameters, and update the point cloud data $Q$ to Equation (7):

$$\Delta G = \exp(\sum_i \xi_i T_i) \tag{7}$$
$$Q \leftarrow \Delta G \cdot Q$$

As shown in Equation (8), the final estimation matrix is the combination of all incremental estimation that calculated in the iteration loop.

$$G_{est} = \Delta G_n \cdots \cdots \Delta G_1 \cdot \Delta G_o \tag{8}$$

### D. The Loss Function

The aim is to search out the best transformation by minimizing the difference between the estimation transformation $G_{est}$ and the forward transformation $G_{gt}$. To avoid possible logarithmic operation of the function during the training process and improve the computational efficiency, the objective function in Eq. (9) is used.

$$\left\| (G_{est})^{-1} \cdot G_{gt} - I_4 \right\|_F \tag{9}$$

## III. EXPERIMENTAL RESULTS AND DISCUSSIONS

### A. The Experimental Details

The experiments are designed by using the point cloud data of the Stanford University and the Geometry Center for training [32]. The maximum number for iterations is 80. Other parameters are set to be the best according to the reference [19].

Two classical global methods and two advanced deep learning-based methods are used to compare the registration performance, i.e., the ICP method [33], the histogram based registration method (3DHoPD) [34], the 3DSmoothNet [30], and the PointNet LK [35].

As shown in the Eq. (10), the Root Mean Square Error (RMSE) is selected as the error measurement for its popularity in point cloud registration. It refers to the average square summation of the distance between the corresponding points.

$$RMSE = \sqrt{\frac{1}{N} \sum_{i=1}^{N} \left\| P_i - Q_j \right\|^2}, (1 \le j \le M) \tag{10}$$

where $P_i$ and $Q_j$ are the pairwise nearest neighbors in the two datasets. $N$, $M$ is the scale parameter, respectively. The smaller RMSE means the better result.

Actually, only the RMSE is not enough to know the number of aligned points. The Effective Root Mean Square Error (ERMSE) can better describe the registration accuracy. How to calculate the ERMSE is show in Eq. (11).

$$\begin{cases} \beta = (N-k)/N \\ ERMSE = \sqrt{\dfrac{1}{N-k}\sum_{i=1}^{N}\left\|P_i - Q_j\right\|^2}, (1 \le \text{j} \le \text{M}) \end{cases} \quad (11)$$

where $\beta$ is the ratio of the aligned points to all the points, $k$ is the number of non-aligned points, $N$ is the number of all the points.

### B. The Results and Discussion

Firstly, a test on the learned model by using the open ModelNet40 dataset [36-40] is implemented. The intermediate results in the iterations are shown in Fig. 5. After the model is trained, when the new registration data is input, it can be seen that as the iterations increase, the alignment from the source points to the target points can be well obtained, even if the data is not used to train the model, demonstrating the proposed method is robust enough and has the good feasibility and generalization.



Iteration number of 0    Iteration number of 20

Iteration number of 40    Iteration number of 60
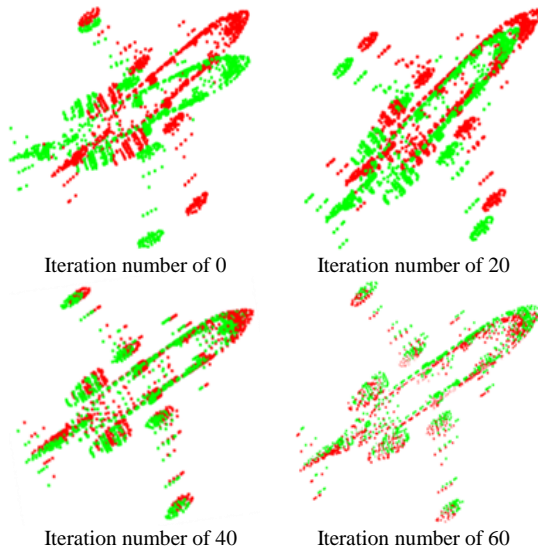
Fig. 5. The registration procedure in different iterations.

Then, the ICP, 3DHoPD, 3DSmoothNet, PointNetLK and the proposed method are tested on the four models that are shown in Fig. 6. The blue points are the source points, and the yellow points are target points. All the visual registration results are shown in Fig. 7 and the quantitative comparison results are shown in Table I to Table IV. The deviation of the initial attitude is significant for the data in Model 1 and Model 2. It can be found from Fig. 7 that the ICP and the 3DHoPD perform very poor on these two datasets, even the registration is failed. From the value of $\beta$ in Table I and Table II, it means only few corresponding points are obtained. In addition, the value of the RMSE and the ERMSE is obviously larger than that of the other three methods, showing the traditional global registration cannot well deal with the significant attitude deviation. On the other hand, the tree methods using the deep learning theory perform well on the two dataset, especially the proposed method can get the best ratio of 89.2%, which means most of the corresponding points are obtained. This is because the important structural features

in the deep levels can be effectively captured. The superiority is obvious to deal with the attitude deviation problem.

For the data in Model 3 and Model 4, they mainly focus on the translation when the partial overlap happens. It can be found that the ICP and the 3DHoPD perform better than their performance in Model 1 and Model 2; the value of $\beta$ in Table III and Table IV showing more corresponding points can be obtained. Of all the five registration methods, the proposed method achieves the best quantitative comparison and the highest accuracy is 93.52%, improving five percent compared with the ICP method. Overall, the proposed method can achieve sufficiently good results for both of the translation and rotation in the registration, demonstrating stronger robustness, better generalization and higher accuracy.

TABLE I. THE REGISTRATION RESULTS OF MODEL 1

| Method | RMSE | β | ERMSE |
|---|---|---|---|
| ICP | 0.6673 | 0.0603 | 0.6676 |
| 3DHoPD | 0.3391 | 0.3610 | 0.4451 |
| 3DSmoothNet | 0.1360 | 0.5513 | 0.1540 |
| PointNetLK | 0.0843 | 0.8704 | 0.0631 |
| Proposed | 0.0531 | 0.8920 | 0.0615 |



Model 1    Model 2

Model 3    Model 4
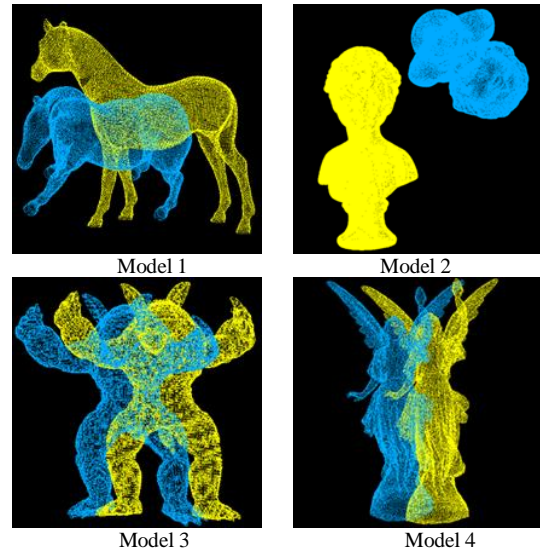
Fig. 6. The four models of the point cloud.

TABLE II. THE REGISTRATION RESULTS OF MODEL 2

| Method | RMSE | β | ERMSE |
|---|---|---|---|
| ICP | 0.5664 | 0.0045 | 0.5861 |
| 3DHoPD | 0.2168 | 0.2550 | 0.2476 |
| 3DSmoothNet | 0.0158 | 0.7655 | 0.0169 |
| PointNetLK | 0.0098 | 0.8612 | 0.0112 |
| Proposed | 0.0075 | 0.8823 | 0.0985 |

TABLE III. THE REGISTRATION RESULTS OF MODEL 3

| Method | RMSE | β | ERMSE |
|---|---|---|---|
| ICP | 0.0038 | 0.8870 | 0.0046 |
| 3DHoPD | 0.0036 | 0.8939 | 0.0045 |
| 3DSmoothNet | 0.0034 | 0.9053 | 0.0043 |
| PointNetLK | 0.0032 | 0.9171 | 0.0040 |
| Proposed | 0.0030 | 0.9280 | 0.0033 |

TABLE IV.    THE REGISTRATION RESULTS OF MODEL 4

| Method | RMSE | β | ERMSE |
|---|---|---|---|
| ICP | 0.0076 | 0.8935 | 0.0078 |
| 3DHoPD | 0.0065 | 0.9089 | 0.0066 |
| 3DSmoothNet | 0.0056 | 0.9110 | 0.0058 |
| PointNetLK | 0.0050 | 0.9286 | 0.0052 |
| Proposed | 0.0045 | 0.9352 | 0.0050 |



(a) ICP    (b) 3DHoPD    (c) 3DSmoothNet    (d) PointNetLK    (e) Proposed
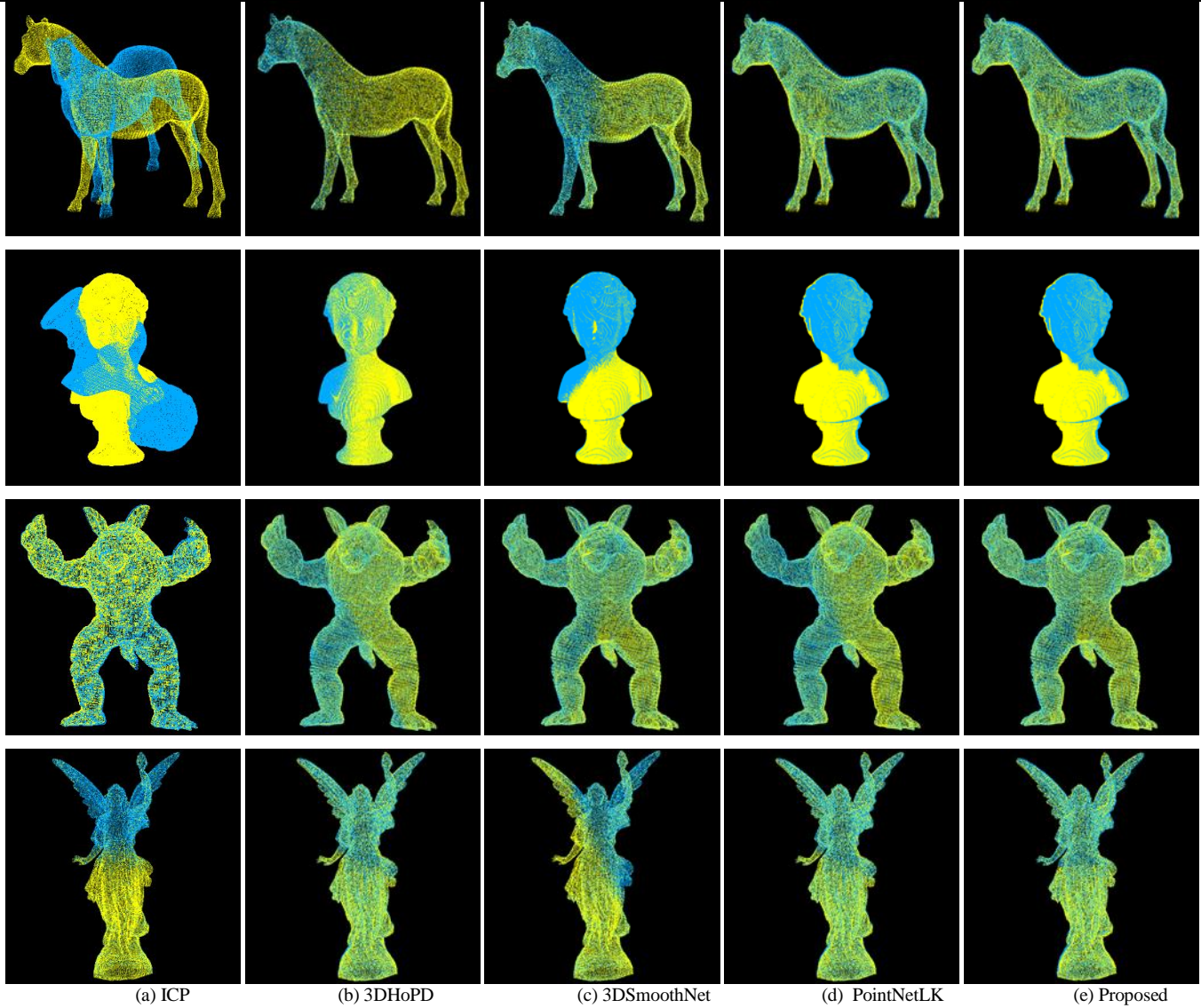
Fig. 7.    The registration results of different methods.

TABLE V.    THE RUNNING TIME OF DIFFERENT METHODS

| Method | Model 1 | Model 2 | Model 3 | Model 4 |
|---|---|---|---|---|
| ICP | 13.25 | 15.85 | 3.85 | 3.88 |
| 3DHoPD | 13.13 | 15.45 | 3.65 | 3.70 |
| 3DSmoothNet | 12.07 | 14.15 | 16.30 | 24.15 |
| PointNetLK | 2.96 | 3.50 | 3.86 | 6.04 |
| Proposed | 1.63 | 1.91 | 2.20 | 3.31 |

The time cost of the five methods on the four models is also shown in Table V (*time/s*). It can be found that when dealing with the significant deviation of the initial attitude in Model 1 and Model 2, the proposed method achieves almost 8 times faster than the ICP method and 3DHoPD method, 7 times faster than the 3DSmoothNet method and 1.5 times faster than the PointNetLK method. When deal with the partial overlap problem in Model 3 and Model 4, the time cost of the ICP, 3DHoPD is almost the same, the 3DSmoothNet spends

the most time, and the proposed method achieves at least 1.6 times faster than the PointNetLK method. Therefore, both of the qualitative and quantitative analysis on experimental results show the superiority and feasibility.

## IV. CONCLUSION AND FUTURE WORK

A novel point cloud registration method by using the coarse-to-fine strategy is developed. This method integrates the improved RANSAC algorithm and the LK algorithm into the PointNet network, effectively avoiding the inherent defect that the PointNet network cannot adapt to the gradient estimation through convolutions. In addition, the proposed method reduces the attitude difference and partial overlap between the source point cloud datasets by simultaneously making use of the global and local features. Experimental results obtained by four state-of-the art methods on four datasets fully verify its effectiveness, accuracy and superiority.

Though good results have been obtained, some limitations should be fixed, such as the extracted features are not rich enough, the registration accuracy is not satisfying and the time cost is still too high to apply it in practice. In future work, the proposed method will be further optimized by introducing advanced theory and applying it to other registration tasks. For example, the famous transformer model and attention mechanism will be employed to extract more deep features to improve the registration performance.

## CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest to report regarding the present study.

## REFERENCES

[1] J. Kim, M.G. Gwon, H. Park, H. Kwon, G.M. Um, and W. Kim, "Sampling is Matter: Point-guided 3D Human Mesh Reconstruction," in Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition, 2023, pp. 12880-12889.

[2] Z. Liu, L. Wang, M. Tahir, et al., "An Improved Poisson Surface Reconstruction Algorithm based on the Boundary Constraints" International Journal of Advanced Computer Science and Applications(IJACSA), vol.14, no.1, pp. 225-232, 2023.

[3] M.Inkarbekov, R. Monahan and B.A. Pearlmutter, "Visualization of AI Systems in Virtual Reality: A Comprehensive Review" International Journal of Advanced Computer Science and Applications(IJACSA), vol.14, no. 8, pp. 33-42, 2023.

[4] Y. Zhao and T. Guo, "Pointar: Efficient lighting estimation for mobile augmented reality," in Proceedings of the European Conference on Computer Vision(ECCV), Glasgow, UK, August 23-28, 2020, Springer, pp. 678-693.

[5] T. Liang, H. Xie, K.Yu, et al., "Bevfusion: A simple and robust lidar-camera fusion framework," Advances in Neural Information Processing Systems, vol. 35, pp. 10421-10434, 2022.

[6] S. Garg and M. Milford, "SeqNetVLAD vs PointNetVLAD: Image Sequence vs 3D Point Clouds for Day-Night Place Recognition," arXiv preprint arXiv:2106.11481, 2021.

[7] J. Chen, H. Shi, Y. Ye, K. Yang, L. Sun, and K. Wang, "Efficient human pose estimation via 3d event point cloud," in Proceedings of the IEEE International Conference on 3D Vision (3DV), 2022, IEEE, pp. 1-10.

[8] X. Huang, G. Mei, J. Zhang, and R. Abbas, "A comprehensive survey on point cloud registration," arXiv preprint arXiv:2103.02690, 2021.

[9] D. Lu, X. Lu, Y. Sun, and J. Wang, "Deep feature-preserving normal estimation for point cloud filtering," Computer-Aided Design, vol. 125, pp. 102860, 2020.

[10] F. Tombari, S. Salti, and L. Di Stefano, "Unique shape context for 3D data description," in Proceedings of the ACM Workshop on 3D Object Retrieval, 2010, pp. 57-62.

[11] M. S. Borges, A. W. Vieira, Á. B. Carvalho, and Marcos F.S.V. D'Angelo, "Local range image descriptor for general point cloud registration," Multimedia Tools and Applications, vol. 79, pp. 6247-6263, 2020.

[12] R. B. Rusu, N. Blodow, and M. Beetz, "Fast point feature histograms (FPFH) for 3D registration," in Proceedings of the IEEE International Conference on Robotics and Automation, 2009, IEEE, pp. 3212-3217.

[13] G. Silvera, A. Biswas, and H. Admoni, "DReye VR: Democratizing Virtual Reality Driving Simulation for Behavioural & Interaction Research," in Proceedings of the 17th ACM/IEEE International Conference on Human-Robot Interaction (HRI), 2022, IEEE, pp. 639-643.

[14] D. Aiger, N. J. Mitra, and D. Cohen-Or, "4-points congruent sets for robust pairwise surface registration," ACM Transactions on Graphics, vol. 27, no. 3, pp. 1-10, 2008.

[15] N. Mellado, D. Aiger, and N. J. Mitra, "Super 4PCS fast global pointcloud registration via smart indexing," Computer Graphics Forum, vol. 33, no. 5, pp. 205-215, 2014.

[16] P. W. Theiler, J. D. Wegner, and K. Schindler, "Keypoint-based 4-points congruent sets–automated marker-less registration of laser scans," ISPRS Journal of Photogrammetry and Remote Sensing, vol. 96, pp. 149-163, 2014.

[17] J. Huang, T.-H. Kwok, and C. Zhou, "V4PCS: Volumetric 4PCS algorithm for global registration," Journal of Mechanical Design, vol. 139, no. 11, p. 111403, 2017.

[18] L. Cheng, Y. Chen, and G. Liu, "2PnS-EG: A general two-population n-strategy evolutionary game for strategic long-term bidding in a deregulated market under different market clearing mechanisms," International Journal of Electrical Power & Energy Systems, vol. 142, pp. 108182, 2022.

[19] C. R. Qi, H. Su, K. Mo, and L. J. Guibas, "Pointnet: Deep learning on point sets for 3d classification and segmentation," in Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition, 2017, pp. 652-660.

[20] Y.H. Sahin, O. Karabacak, M. Kandemir, and G. Unal, "ALReg: Registration of 3D Point Clouds Using Active Learning," Applied Sciences, vol.13, no.13, pp.7422, 2023.

[21] Y. Wang and J. M. Solomon, "PRNet: Self-supervised learning for partial-to-partial registration," Advances in Neural Information Processing Systems, vol. 32, pp.1-13, 2019.

[22] C. Choy, W. Dong, and V. Koltun, "Deep global registration," in Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition, 2020, pp. 2514-2523.

[23] X. Huang, G. Mei and J. Zhang, "Feature-Metric Registration: A Fast Semi-Supervised Approach for Robust Point Cloud Registration Without Correspondences," in Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition (CVPR), Seattle, WA, USA, 2020, pp. 11363-11371.

[24] Y. Wang and J. M. Solomon, "Deep closest point: Learning representations for point cloud registration," in Proceedings of the IEEE/CVF International Conference on Computer Vision, 2019, pp. 3523-3532.

[25] Y. Wang, Y. Sun, Z. Liu, S. E. Sarma, M. M. Bronstein, and J. M. Solomon, "Dynamic graph cnn for learning on point clouds," ACM Transactions on Graphics, vol. 38, no. 5, pp. 1-12, 2019.

[26] A. Vaswani, N. Shazeer, N. Parmar, et al., "Attention is all you need," in Proceedings of the 31st International Conference on Neural Information Processing Systems, pp. 6000-6010, 2017.

[27] J. Li, C. Zhang, Z. Xu, H. Zhou, and C. Zhang, "Iterative distance-aware similarity matrix convolution with mutual-supervised point elimination for efficient point cloud registration," in in Proceedings of the European Conference on Computer Vision(ECCV), Glasgow, UK, August 23–28, 2020, pp. 378-394.

[28] Z. J. Yew and G. H. Lee, "RPM-Net: Robust point matching using learned features," in Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition(CVPR), 2020, pp. 11824-11833.

[29] Z. Zhang, J. Sun, Y. Dai, D. Zhou, X. Song and M. He, "A Representation Separation Perspective to Correspondence-Free Unsupervised 3-D Point Cloud Registration," IEEE Geoscience and Remote Sensing Letters, vol. 19, pp. 1-5, 2022.

[30] Z. Gojcic, C. Zhou, J. D. Wegner and A. Wieser, "The Perfect Match: 3D Point Cloud Matching With Smoothed Densities," in Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition (CVPR), Long Beach, CA, USA, 2019, pp. 5540-5549.

[31] M. Zhu, M. Ghaffari, and H. Peng, "Correspondence-free point cloud registration with SO(3)-equivariant implicit shape representations," in Proceedings of the Conference on Robot Learning, 2022, pp. 1412-1422.

[32] The Standford 3D Scanning Repository http://graphics.stanford.edu/data/3Dscanrep/. (Accessed 10 Sept. 2023 )

[33] H. Bai, "ICP Algorithm: Theory, Practice And Its SLAM-oriented Taxonomy," arXiv preprint arXiv:2206.06435, 2022.

[34] S. M. Prakhya, J. Lin, V. Chandrasekhar, W. Lin, and B. Liu, "3DHoPD: A fast low-dimensional 3-D descriptor," IEEE Robotics and Automation Letters, vol. 2, no. 3, pp. 1472-1479, 2017.

[35] Y. Aoki, H. Goforth, R. A. Srivatsan and S. Lucey, "PointNetLK: Robust & Efficient Point Cloud Registration Using PointNet," in Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition (CVPR), Long Beach, CA, USA, 2019, pp. 7156-7165.

[36] S. Jung, Y.-S. Lee, Y. Lee, and K. Lee, "3D reconstruction using 3D registration-based ToF-stereo fusion," Sensors, vol. 22, no. 21, pp. 8369, 2022.

[37] Huang, Jin, Lei Wang, Muhammad Tahir, Tianqi Cheng, Xinping Guo, Yuwei Wang, and ChunXiang Liu. "The Effective 3D MRI Reconstruction Method Driven by the Fusion Strategy in NSST Domain." International Journal of Advanced Computer Science and Applications 14, no. 4 (2023).

[38] Song, Tengteng, YiZhi He, Muhammad Tahir, Jianbo Li, Li Zhao, and Imran Saeed. "Towards Point Cloud Classification Network Based on Multilayer Feature Fusion and Projected Images." International Journal of Advanced Computer Science and Applications 14, no. 6 (2023).

[39] ChunXiang Liu, Jin Huang, Muhammad Tahir, Lei Wang, Yuwei Wang and Faiz Ullah, "The Medical Image Denoising Method Based on the CycleGAN and the Complex Shearlet Transform" International Journal of Advanced Computer Science and Applications(IJACSA), 14(8), 2023. http://dx.doi.org/10.14569/IJACSA.2023.0140814.

[40] Zheng, Xiao, Muhammad Tahir, Mingchu Li, and Shaoqing Wang. "Computational Analysis based on Advanced Correlation Automatic Detection Technology in BDD-FFS System." International Journal of Advanced Computer Science and Applications 13, no. 8 (2022).

# Surface Reconstruction from Unstructured Point Cloud Data for Building Digital Twin

F.A. Ismail[1], S.A. Abdul Shukor[2], N.A. Rahim[3], R. Wong[4]

Faculty of Electrical Engineering & Technology, Universiti Malaysia Perlis, Arau, 02600, Perlis, Malaysia[1, 2, 3]
Centre of Excellence for Intelligent Robotics & Autonomous System,
Universiti Malaysia Perlis, Arau, 02600, Perlis, Malaysia[1, 2, 3]
Geodelta Systems Sdn. Bhd., Damansara Utama, 47400 Petaling Jaya, Selangor, Malaysia[4]

*Abstract*—**This study highlights on the methods used for surface reconstruction from unstructured point cloud data, characterized by simplicity, robustness and broad applicability from 3D point cloud data. The input data consists of unstructured 3D point cloud data representing a building. The reconstruction methods tested here are Poisson Reconstruction Algorithm, Ball Pivoting Algorithm, Alpha Shape Algorithm and 3D surface refinement, employing mesh refinement through Laplacian smoothing and Simple Smoothing techniques. Analysis on the algorithm parameters and their influence on reconstruction quality, as well as their impact on computational time are discussed. The findings offer valuable insights into parameter behavior and its effects on computational efficiency and level of detail in the reconstruction process, contributing to enhanced 3D modeling and digital twin for buildings.**

*Keywords—Surface reconstruction; point cloud; building reconstruction; 3D mesh*

## I. INTRODUCTION

Buildings play a pivotal role in our everyday lives, and consequently, considerable endeavors have been directed towards enhancing them. One approach to achieve this enhancement involves integrating digital technologies throughout the entire life cycle of the building, encompassing various stages such as planning, construction, operation, renovation and demolition [1]. Notably, significant attention has been dedicated to integrating digital advancements into the construction life cycle in the past decade [2]. Throughout this life cycle, three-dimensional (3D) models have demonstrated their utility in facilitating decision-making, scenario modeling, and analysis of 3D data. In recent years, there has been a growing demand for effective and efficient monitoring of changes in buildings and construction installations within urban areas. This demand is particularly evident in the domains of architecture, engineering, construction/facility management (AEC/FM), urban planning, surveying and mapping. Various applications, such as progress tracking, profitability enhancement, quality control, security assurance and incident investigation, underscore the necessity for advanced methodologies that employ automated measurements, including 2D imaging, photogrammetry and 3D laser scanning, instead of relying solely on visual inspection and manual data collection.

3D building models are important in representing the urban environment and have numerous applications, including 3D

Geographic Information Systems (GIS), urban planning, environmental simulation, energy consumption assessment, tourism, mobile navigation, heritage preservation and change detection [3]–[5]. Many studies have been conducted throughout the years on the reconstruction of building information models (BIM). BIM, as a valuable methodology, serves as a pivotal tool in facilitating the planning and construction processes of architectural and infrastructural projects. BIM models intricately replicate physical structures, offering a comprehensive foundation for undertaking assessments of their status, condition, and strategizing maintenance activities. Furthermore, BIM presents a unified and cohesive platform for the seamless integration of data collected from the construction site.

Recently, the concept of BIM has expanded to include the concept of a digital twin (DT). DT is a virtual representation of a physical entity that used to simulate and evaluate the performance of a building throughout its lifespan. The digital twin technology can be utilized for various purposes such as visualization, modelling, simulation, analysis and future planning [6], [7]. These virtual models can help optimize the design and building process, anticipate potential issues and enhance the building's performance and features over time [8]. The idea of a digital twin was initially introduced by M. Grieves during a Product Life-Cycle Management Symposium at the University of Michigan Lurie Engineering Center in 2002 [9]. The proposed model of a digital twin comprises three primary components: the physical product, the virtual product and the connection between the physical and virtual entities. In a subsequent publication [10], Grieves further defined digital twinning as the integration of three essential elements: a virtual twin, a physical counterpart (such as a product, system, model, or entity like a robot, car, power turbine, human, hospital, etc.), and a data flow cycle that facilitates the exchange of information between the physical and virtual twins. The virtual twin employs simulation algorithms to replicate (either fully or partially) the performance of its physical counterpart, generating equivalent outputs based on input values. This technology is commonly used in the context of smart manufacturing but is applicable to various domains, including construction, education, transportation, human and healthcare, also industrial production [7]. The primary advantages of digital twin models are their ability to access and query structured data and their visual representation of information. Digital twins undergo periodic updates to maintain alignment with their physical counterparts. The frequency of these

updates varies contingently upon factors including the inherent characteristics of the product, its dynamic attributes and the specific objectives underlying the model's use. For instance, in the case of a jet engine, updates may occur at minute intervals, whereas for maintenance management of a building, annual updates may suffice. Notwithstanding, a notable complexity emerges due to the historical context of many extant buildings, often constructed decades ago, thereby necessitating the development of digital twin models that accurately represent these pre-existing assets.

To create a digital twin of a building, one of the essential steps is to capture its geometry and appearance using point cloud data. A point cloud is a collection of points in 3D space that represent the surface of an object. These data points typically comprise X, Y, and Z coordinates and are primarily utilized to depict the outer surfaces of an entity [11]. Point clouds can be obtained from various sources, such as laser scanners or cameras, by capturing the geometry of an existing facility. These techniques produce point cloud data as output. Compared to visual inspection, point cloud data offers shorter processing times and higher measurement accuracy. With the introduction of very precise data collection techniques involving terrestrial laser scanning, aerial oblique photography and satellite imagery, 3D point cloud has established itself as the principal data sources for large-scale building reconstruction. Point clouds can be processed and reconstructed to create 3D models of building interiors and exteriors in vector format. Furthermore, existing research projects have emerged proposing approaches for generating accurate building footprints and models by combining point clouds and imaging [12]–[14]. This interdisciplinary field, which includes photogrammetry, computer vision and modelling, has seen significant research efforts over the last two decades, delivering important and significant results.

While 3D building models and digital twins offer immense potential in urban development and architectural landscapes, there exists a notable gap in systematically and critically analyzing the various surface reconstruction techniques that form the foundation of these models especially on its simplicity, robustness, and broad applicability in surface reconstruction from point cloud data. This paper aims to bridge this research gap by addressing the following pivotal questions: (a) How does different surface reconstruction technique perform when applied to large, unstructured point cloud data like buildings, both in terms of quality and speed of calculation? and (b) In what contexts do these techniques exhibit optimal efficiency and precision? This paper central contribution is an in-depth comparative assessment of specific surface reconstruction techniques, bringing clarity to the challenges, advantages, and nuances of each. In doing so, professionals and researchers in the related field could equip with a clearer understanding and guide for their practical and academic endeavors.

In existing research, a rich set of methods has been proposed for surface reconstruction from point clouds, and some reviews and benchmarks of these methods have also been provided [15]. However, they still face challenges in terms of robustness, generalization and efficiency, especially for unstructured, complex and large-scale surfaces such as buildings. Furthermore, the scalability and parallelizability of these methods become critical when dealing with big data, as they must handle enormous point cloud collections while maintaining computational efficiency. Point cloud-based 3D reconstruction in buildings has many applications for the construction industry, such as automatic creation of as-built BIMs, damage detection and assessment, cultural heritage, and facility management [16]–[18]. Therefore, there is a need for developing an effective method for surface reconstruction from point clouds that can handle the specific characteristics and requirements of building surfaces.

This paper focuses on a few types of surface reconstruction techniques use for building data. Thus, a comparison between these techniques, based on the quality of the surfaces and the speed of calculation, will be made. This work is organized as follows: Section II presents a summary of reconstruction methods from a set of discrete data points or sample. Section III shows the visualization and discussion of the surface reconstruction results for more understanding. Lastly, Section IV explains the conclusion for this paper.

## II. METHODOLOGY

The overview of the sample data used for reconstructing 3D surface of a building is as shown in Fig. 1. The point cloud data represents one of the buildings in Faculty of Electrical Engineering & Technology, Universiti Malaysia Perlis, Malaysia. The initial step involves converting the binary data into a more interpretable format compatible with standard 3D libraries and applications. Subsequently, downsampling the data is performed to make it efficiently better processed with shorter computational time. Next, data cleaning is implemented to mitigate imperfections in the real data, enhancing the efficiency of the surface reconstruction method for mesh generation. Finally, five different surface reconstruction techniques are applied and assessed based on the resulting processed point cloud data to generate a 3D triangulated mesh.

### A. The Sample Data

The point cloud data of 3D coordinates is stored in six different files and saved in .ptx file format and consists of approximately 226,471,204 points. The data is collected by Geodelta Systems Sdn. Bhd. using 3D terrestrial laser scanner model Leica RTC360 where it has a scanning speed up to 2 million pts/sec and advanced HDR imaging.

To extract the 3D file format from the .ptx file and transform it into a commonly used 3D point cloud data format, such as the .pcd file format, a comprehensive understanding of the binary file data structure assumes paramount significance. Each .ptx file encompasses vital data elements, encompassing color information, the minimum depth value (zmin), the subsampled number of rows (nrows), the subsampled number of columns (ncols), the image file name, and an Nx5 matrix signifying 3D and 2D normalized coordinates falling within the [0,1] range [19]. Herein, N denotes the product of nrows and ncols, where values equivalent to zmin denote the background. The extraction process selectively focuses on the isolation and preservation of solely the 3D coordinates from the .ptx file, ultimately saving them in the .pcd file format, facilitating subsequent analytical endeavors. Various software tools, such

as CloudCompare, MeshLab, Blender and Python 3D libraries, can read the .pcd file format, facilitating data visualization and manipulation. This enables easier understanding and modification of the data as needed. An example of an extracted point cloud dataset is illustrated in Fig. 1, where the image at the below shows a zoomed-in view of the original 3D point cloud shown on the top. From the figure, it can be inferred that each point exhibits ambiguous relationships with neighbouring points.
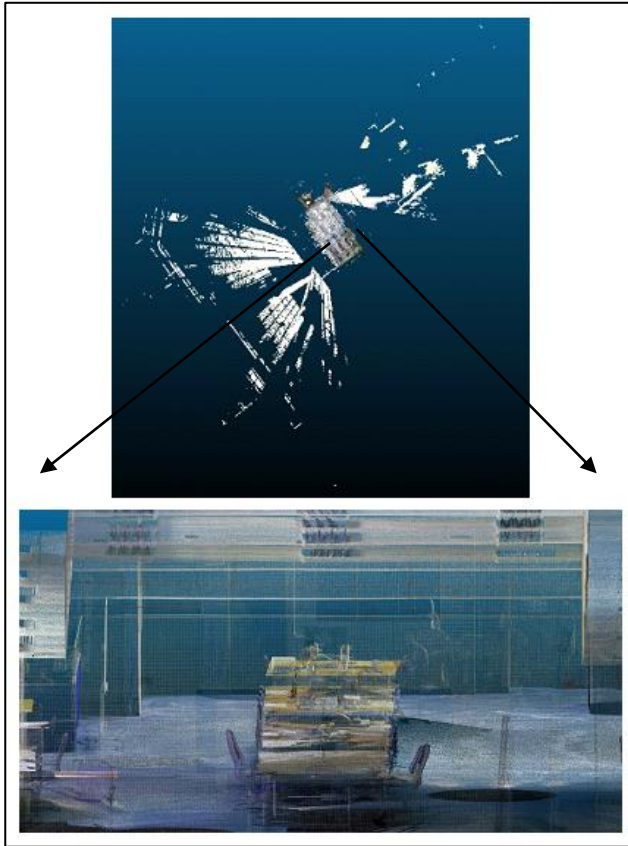


Fig. 1.  The point cloud data used in this study.

### B.  Data preprocessing

In order to improve the data quality and computational efficiency, a preprocessing stage is employed to eliminate unnecessary data of point clouds. One of the often used as a pre-processing step for many point cloud data processing tasks is voxel downsampling. Downsampling is a technique to reduce the number of points in a point cloud as the original dataset is too large to handle. It can improve efficiency and accuracy by minimizing storage requirements, processing time and memory usage. One of the common methods for downsampling is voxel downsampling. It uses a regular voxel grid to create a uniformly downsampled point cloud from an input point cloud. The algorithm follows a two-step process: initially, data points are grouped into voxel containers and subsequently, each occupied voxel yields a single representative point through the computation of the average of all points contained within it. So, all of the point clouds are being downsampled to 0.01 resulted in easier to be processed due to lesser number of points as shown in Fig. 2. The

downsampled point cloud data reduced to 12,704,776 points, from its original which consists of 226,471,204 points.



Fig. 2.  Downsampled data of original point cloud.

Next, the preprocessing step involves removing statistical outliers. It removes points that are further away from their neighboring points. The mean inter-point separation is computed via the application of the k-nearest neighbors algorithm. Should the computed average distance between a query point and its neighboring points surpass a threshold established by the standard deviation, it is categorized as an outlier and subsequently excluded from the dataset. This initial preprocessing stage employs various standard deviation ratios, notably a factor of 0.75, to accentuate differentiation. The parameter kNN, signifying the number of nearest neighbors considered, is set to a value of 50. Fig. 3 shows the visualization of the point cloud data with red and grey colour that indicates the outlier and inlier. The red colour is the outliers that being filtered out. Fig. 4 shows the remaining point cloud in original colour of 12,225,180 points.
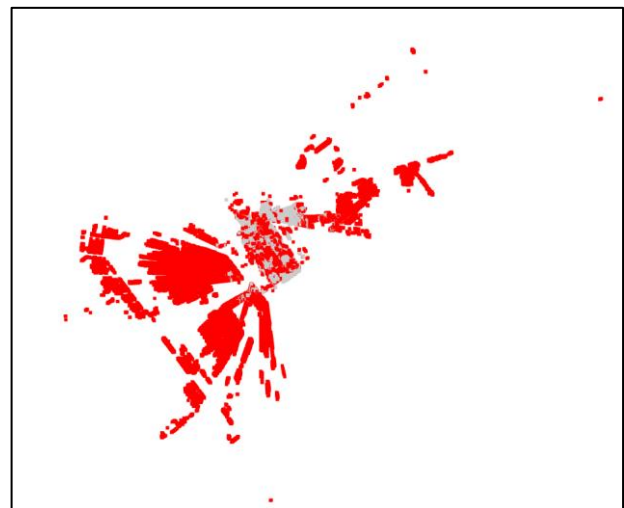


Fig. 3.  Inlier (in grey) and outlier (in red) of the point cloud data.
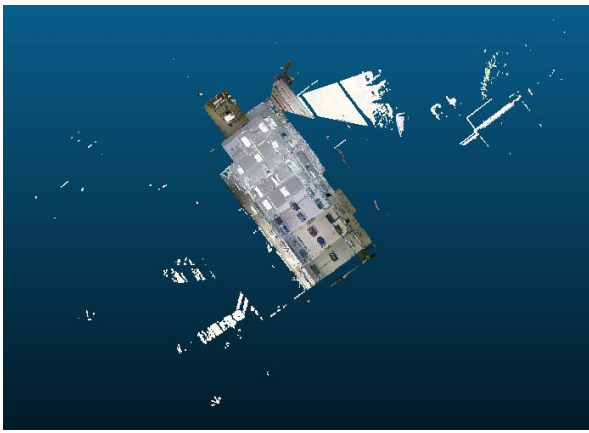
Fig. 4. Remaining point cloud after outlier removal.

However, the remaining point clouds are not accurate as the surrounding of the buildings still contains points that are considered as noise. So, a process of filtering takes over using CloudCompare by manually remove the excessive point cloud surrounding the building. Fig. 5 below shows the remaining point cloud data that will be processed for surfacce reconstruction which only consist of 7,258,055 points.



Fig. 5. Filtered point cloud.

*C. Surface reconstruction*

The field of geometry processing has significant emphasis on the foundational challenge of surface reconstruction from point clouds. This endeavor is rooted in the objective of generating a continuous 2D manifold surface from the inherent sparsity of raw, discrete point cloud data. It is worth noting that this problem is inherently ill-posed, and its complexity escalates when considering the various sensor-related imperfections that manifest within point clouds acquired through real-world depth scanning techniques.

Hence, this paper will focus exclusively on five distinct surface reconstruction approaches, aimed at visualizing a range of methodologies advanced by prior researchers addressing this issue. These methodologies can be broadly categorized into three primary groups, namely Alpha Shape, Ball Pivoting and Poisson reconstruction, as well as combinations of Alpha Shape with Ball Pivoting and the amalgamation of Alpha Shape, Ball Pivoting and mesh refinement.

The Alpha Shape technique serves as an extension of the convex hull method, allowing for the representation of point clouds with concavities and holes. However, choosing an appropriate value for "α" requires a balance. If the value is too small, the resulting mesh may include more noise or artifacts, and it may overfit to local irregularities in the point cloud. On the other hand, if the value is too large, the resulting mesh may oversimplify the shape and fail to capture fine details or concavities. By adjusting the parameter alpha or "α", the level of detail in the reconstructed surface can be controlled. A smaller "α" value results in a more intricate surface, while a larger "α" value produces a smoother and simpler surface. The reconstruction process involves computing the Delaunay tetrahedralization of the point cloud and extracting the faces belonging to the "α" complex as it contains points, edges, triangles and tetrahedrons.

Ball Pivoting Algorithm (BPA), another surface reconstruction method, is closely related to the Alpha Shape technique. It is an efficient surface reconstruction approach which operates by simulating the rolling of a ball with a predetermined radius across the point cloud. Triangles are created whenever the ball encounters three points without penetrating them. As the ball moving through the point cloud, a triangular interconnected 3D mesh is formed, linking the 3D points. The method is repeated until all the points form a triangle. Starting with a seed triangle, the algorithm pivots the ball around the edges of existing triangles until all feasible triangles are produced. The BPA exhibits sensitivity to variations in the ball radius, which plays a crucial role in determining the quantity of reconstructed faces. A smaller radius renders the model susceptible to noise in the input data, while a larger radius may lead to the missing of intricate details, resulting in the formation of holes within the generated surface. BPA is suitable for handling point clouds with non-uniform densities and noise; however, careful selection of the ball radius is crucial to prevent gaps or overlaps in the reconstructed surface.

Poisson reconstruction is a widely recognized approach for generating smooth surfaces from point clouds using a volumetric strategy. It leverages oriented point samples obtained from 3D range scanners to create watertight surfaces. The method assumes that the point cloud serves as a sample of an underlying surface's indicator function and solves for an implicit function whose gradient best aligns with the estimated normals of the point cloud. The surface is subsequently extracted as an iso-surface of the implicit function utilizing marching cubes. Poisson reconstruction excels in producing high-quality surfaces with well-defined features, but it requires oriented normals as input and may introduce undesired intricacies in flat regions. Nevertheless, this technique exhibits

resilience to noisy data and artifacts arising from misregistration.

## III. RESULTS AND DISCUSSION

All surface reconstruction techniques were evaluated and tested on a computer system comprising an Intel i7 12700h processor with 32GB of RAM and a GTX 3050ti graphics card. All methods were implemented using the Open3D library in python. Fig. 6 shows the clean point cloud data of the chosen building that will be used for the surface reconstruction algorithms upon preprocessing and Fig. 7 shows the close-up view for the point cloud for better understanding to show its complexity and unstructured of the data. Table I shows the comparison of all algorithms with the parameters used, time taken for each algorithm needs to be completed, together with their resulting images from two views: the whole building and close-up view from the top corner.



Fig. 6. Point cloud data of the building.



Fig. 7. Close-up view of the point cloud.

Poisson surface reconstruction necessitated the prior prediction of normals for surface reconstruction, employing it automatically by the maximum nearest neighbour search. The depth of reconstruction indicated the resolution of the resulting triangle mesh, determined by the octree's depth which being set to 8. The minimum number of sample points within an octree node was established to adapt the octree construction to the sampling process, with lower numbers chosen to mitigate noise interference. The scale factor denoted the ratio between the reconstruction cube's diameter and the sample bounding box's diameter. Nevertheless, Poisson surface reconstruction yielded outcomes without any mesh holes but it leaves unnecessary mesh triangulations on planar point as shown in Table I.

TABLE I. SUMMARY OF RESULT COMPARISON FOR THE SELECTED ALGORITHMS

| Algorithms | Parameters | Processing Time (s) | Results |
|---|---|---|---|
| Poisson Reconstruction | Octree depth=8 Scale factor=1 | 163.92 |  |

| Ball Pivoting | Ball radius=0.02 | 288.34 |  |
| Alpha Shape | α = 0.13 | 303.19 |  |
| Alpha Shape + Ball Pivoting | α = 0.13<br>Ball radius=0.02 | 566.38 |  |

| | | | |
|---|---|---|---|
| | | |  |
| **Alpha Shape + Ball Pivoting + Mesh Filtering** | **α = 0.13 Ball radius=0.02 Number of iterations (Simple Smoothing)=30 Number of iterations (Laplacian)=30 Lambda filter=0.5** | 1092.07 |  |

On the other hand, Ball Pivoting surface reconstruction required prior normal estimation before commencing surface reconstruction. Vertices falling within a given percentage of the clustering radius were merged to prevent excessive small triangle creation. The ball rolling process would cease if it encountered a significant crease angle surpassing the threshold angle. The ball's rolling radius over the point cloud was set to 0.02. Table I exhibited also the outcomes of ball pivoting surface reconstruction, where holes were observed in regions with lower point cloud density. However, unlike Poisson surface reconstruction, this method avoided unnecessary mesh creation that required subsequent cropping since it failed to represent facial depth accurately.

Meanwhile, the result of meshing using the Alpha Shape method with a parameter value of 0.13 involves generating a surface mesh that captures the shape of a point cloud with holes and concavities. The Alpha Shape method is a generalization of the convex hull and is particularly useful when dealing with point clouds that have irregular or non-convex shapes. Unlike Poisson and Ball Pivoting, Alpha Shape algorithm does not require normal estimation. The parameter "α" in the Alpha Shape method determines the level of detail in the reconstructed surface. A smaller value of "α" (0.13) produces a more detailed mesh with a higher resolution where

smaller features and intricate details present in the point cloud can be captured in the resulting mesh as shown in Table I. The mesh will closely follow the shape of the input point cloud and adapt to its local density and curvature. Therefore, the choice of the "α" parameter is decided after running several tests with different values. This gives the best result as it still can capturing details and maintaining the overall shape fidelity in the resulting mesh.

Due to the limitations of each individual algorithm, the combination of Ball Pivoting and Alpha Shape methods in meshing involves leveraging the strengths of both approaches to achieve a more robust and accurate representation of the underlying point cloud. By combining Ball Pivoting and Alpha Shape methods, the strengths of both techniques can be fully utilized. Ball Pivoting handle the local details and irregularities of the point cloud, while Alpha Shape capture the overall shape and handle concavities. This combined approach produced a mesh that preserves the important features and characteristics of the original point cloud, while also providing a more accurate and visually appealing representation as shown. However, the Alpha Shape results in not so precise reconstruction when it comes to sharpness of angles of the building as shown in Table I.

The integration of Ball Pivoting, Alpha Shape and mesh refinement through Laplacian smoothing and Simple Smoothing however constitutes a comprehensive strategy for the task of surface reconstruction and subsequent mesh enhancement. In terms of mesh refinement, two distinct smoothing techniques are employed. Laplacian smoothing involves iterative adjustments of vertex positions, effectively attenuating high-frequency noise and enhancing mesh smoothness while preserving sharp geometric features. Conversely, Simple Smoothing employs a rudimentary moving average filter to vertices, delivering a general refinement to the mesh's geometric properties. This two-fold smoothing methodology serves the purpose of mitigating undesired irregularities and augmenting the overall visual fidelity of the mesh representation. Through the combination of these methodologies, the resultant mesh stands to gain advantages in terms of heightened accuracy, diminished noise, and improved surface regularity. The amalgamation of Ball Pivoting, Alpha Shape, and the aforementioned dual smoothing techniques yields a potent solution applicable across diverse domains, encompassing computer graphics, 3D modeling, virtual reality, and computational geometry. Furthermore, the adaptability inherent in this combined approach empowers users to fine-tune parameters and iteration counts, thereby achieving optimal outcomes tailored to the distinctive attributes of their datasets and the desired level of mesh refinement. Consequently, this combination of methodologies emerges as an efficacious and versatile technique for addressing surface reconstruction and mesh refinement tasks.

In summary, each of the methodologies introduced for surface reconstruction has its respective advantages and limitations. The Poisson surface reconstruction method consistently produces hole-free results but can also introduce unnecessary triangulations. On the other hand, the Ball Pivoting method excels in avoiding unnecessary mesh production yet lacks in representing facial depth precision. The Alpha Shape method, adaptable to non-convex and irregular shapes, offers a versatile solution to meshing, though it may occasionally compromise the precision of angles. However, it becomes evident that the approach emerges from the integration of Ball Pivoting, Alpha Shape, and mesh refinement techniques, specifically through the incorporation of Laplacian and Simple Smoothing. This combination technique harnesses the unique strengths of each individual method, producing an optimal solution that balances accuracy, noise mitigation, and enhanced surface consistency. As a result, this integrated methodology stands out as the most recommended, providing unparalleled robustness and adaptability suitable for a wide range of surface reconstruction and mesh refinement applications.

Upon analyzing the results obtained, it becomes imperative to consider the scalability of the proposed methodologies. While the techniques have shown promising outcomes on the datasets in this study, there is an important area of evaluation to consider. Their performance across datasets that represent distinct architectural styles, varying scales, and diverse complexities needs to be examined. Future investigations should focus on evaluating these methods across a wider range of datasets. This approach will help validate the adaptability and universality of the proposed techniques. In scenarios where the datasets are vast and depict intricate urban landscapes, it is vital to assess metrics such as computational efficiency, memory requirements, and the fidelity of the resultant mesh.

Additionally, despite the promising outcomes, there exist potential limitations and areas for further exploration. One foreseeable challenge pertains to highly intricate and ornate architectural designs, where capturing every minute detail could strain the computational resources and necessitate further algorithmic optimizations. Moreover, while the combination of Ball Pivoting and Alpha Shape methods harnesses their collective strengths, there remains room for improvement in handling sharp angles, as evidenced in Table I. Future research could just focus on refining these combinations, possibly integrating other meshing algorithms or advanced smoothing techniques to better address such challenges. Furthermore, with the rapid evolution of hardware and software capabilities, exploring the integration of machine learning or AI-driven approaches in the surface reconstruction pipeline could offer innovative solutions, enhancing the accuracy and efficiency of the process.

## IV. CONCLUSION

In conclusion, the successful implementation of specific surface reconstruction methods is contingent upon satisfying the input requirements, such as having normal orientation information available for the point cloud. In cases where the input lacks normal orientation, an algorithm must be employed to estimate the orientation values for the point cloud. For instance, Poisson surface reconstruction necessitates the estimation of normal orientations prior to the reconstruction process. Certain methods exhibit robustness towards specific types of point cloud artifacts, including noisy data, nonuniform sampling, outliers, misaligned scans and missing or incomplete data. However, certain methods may be limited in their applicability to different shape classes. For instance, surface reconstruction cannot handle shape classes that do not result in watertight meshes. The output of the reconstruction process can manifest in various forms, such as producing watertight meshes, mesh triangulation on planar surfaces, generating cloth-like meshes that envelop the initial point cloud or voxelization. The result of Poisson surface reconstruction often presents unnecessary mesh triangulations on planar point clouds, resembling cloth-like structures, while effectively closing holes in sparsely sampled regions. On the other hand, Ball Pivoting surface reconstruction tends to yield accurate mesh edges but can leave numerous holes due to nonuniform sampling and missing data, particularly in areas like the angle's region with less point cloud. By combining different methods, it can help to achieve smoother with higher accuracy of the surface of buildings.

REFERENCES

[1] R. G. Kippers, M. Koeva, M. Van Keulen, and S. J. Oude Elberink, "Automatic 3D building model generation using deep learning methods based on CityJSON and 2D floor plans," in International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives, International Society for Photogrammetry and Remote Sensing, Oct. 2021, pp. 49–54. doi: 10.5194/isprs-archives-XLVI-4-W4-2021-49-2021.

[2] Q. Meng et al., "A review of integrated applications of BIM and related technologies in whole building life cycle," Engineering, Construction and Architectural Management, vol. 27, no. 8. Emerald Group Holdings Ltd., pp. 1647–1677, Oct. 01, 2020. doi: 10.1108/ECAM-09-2019-0511.

[3] Y. P. Ma, "Extending 3D-GIS district models and bim-based building models into computer gaming environment for better workflow of cultural heritage conservation," Applied Sciences (Switzerland), vol. 11, no. 5, pp. 1–23, Mar. 2021, doi: 10.3390/app11052101.

[4] B. Yang, "Developing a mobile mapping system for 3D-GIS and smart city planning," Sustainability (Switzerland), vol. 11, no. 13, Jul. 2019, doi: 10.3390/su11133713.

[5] M. Awrangjeb, S. A. N. Gilani, and F. U. Siddiqui, "An effective data-driven method for 3D building roof reconstruction and robust change detection," Remote Sens (Basel), vol. 10, no. 10, Oct. 2018, doi: 10.3390/rs10101512.

[6] M. Enders, M. R. Enders, and N. Hoßbach, "Dimensions of digital twin applications-A literature review," 2019. [Online]. Available: https://www.researchgate.net/publication/359715537

[7] M. Liu, S. Fang, H. Dong, and C. Xu, "Review of digital twin about concepts, technologies, and industrial applications," J Manuf Syst, vol. 58, pp. 346–361, Jan. 2021, doi: 10.1016/j.jmsy.2020.06.017.

[8] H. H. Hosamo, H. K. Nielsen, A. N. Alnmr, P. R. Svennevig, and K. Svidt, "A review of the digital twin technology for fault detection in buildings," Frontiers in Built Environment, vol. 8. Frontiers Media S.A., Nov. 09, 2022. doi: 10.3389/fbuil.2022.1013196.

[9] Michael Grieves, Complex Systems Engineering: Theory and Practice. Reston, VA: American Institute of Aeronautics and Astronautics, Inc., 2019. doi: 10.2514/4.105654.

[10] Michael Grieves, "Digital Twin: manufacturing excellence through virtual factory replication," White paper, vol. 1, pp. 1–7, 2014.

[11] M. Rashidi, M. Mohammadi, S. S. Kivi, M. M. Abdolvand, L. Truong-Hong, and B. Samali, "A decade of modern bridge monitoring using terrestrial laser scanning: Review and future directions," Remote Sensing, vol. 12, no. 22. MDPI AG, pp. 1–34, Nov. 02, 2020. doi: 10.3390/rs12223796.

[12] F. Wang et al., "Reconstruction of LoD-2 building models guided by Façade Structures from Oblique Photogrammetric Point Cloud," Remote Sens (Basel), vol. 15, no. 2, Jan. 2023, doi: 10.3390/rs15020400.

[13] A. Jamali, P. Kumar, and A. Abdul Rahman, "Automated extraction of buildings from aerial lidar point clouds and digital imaging datasets," in International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives, International Society for Photogrammetry and Remote Sensing, Oct. 2019, pp. 303–308. doi: 10.5194/isprs-archives-XLII-4-W16-303-2019.

[14] S. Cao, D. Hu, W. Zhao, M. Du, Y. Mo, and S. Chen, "Integrating multiview optical point clouds and multispectral images from ZiYuan-3 satellite remote sensing data to generate an urban digital surface model," J Appl Remote Sens, vol. 14, no. 01, p. 1, Jan. 2020, doi: 10.1117/1.jrs.14.014505.

[15] R. Sharma and P. Abrol, "Parameter extraction and performance analysis of 3D surface reconstruction techniques," International Journal of Advanced Computer Science and Applications, vol. 14, no. 1, pp. 331–336, 2023, doi: 10.14569/IJACSA.2023.0140135.

[16] V. Stojanovic, M. Trapp, R. Richter, B. Hagedorn, and J. Döllner, "Towards the generation of digital twins for facility management based on 3D point clouds," 2018.

[17] Y. Zhou, S. Shen, and Z. Hu, "Detail preserved surface reconstruction from point cloud," Sensors (Switzerland), vol. 19, no. 6, Mar. 2019, doi: 10.3390/s19061278.

[18] Q. Wang and M. K. Kim, "Applications of 3D point cloud data in the construction industry: A fifteen-year review from 2004 to 2018," Advanced Engineering Informatics, vol. 39. Elsevier Ltd, pp. 306–319, Jan. 01, 2019. doi: 10.1016/j.aei.2019.02.007.

[19] M. A. Zuraimi, F. H. K. Zaman, and L. Mazalan, "3D human face surface reconstruction from unstructured point cloud face images," in 2022 IEEE 13th Control and System Graduate Research Colloquium, ICSGRC 2022 - Conference Proceedings, Institute of Electrical and Electronics Engineers Inc., 2022, pp. 165–170. doi: 10.1109/ICSGRC55096.2022.9845175.

# A Cost-Effective Method for Detecting and Tracking Moving Objects using Overlapping Methods

Yuanyuan ZHANG[1*]

College of Economic and Management, North China Institute of Science and Technology
Langfang, Hebei 065201, China

*Abstract*—**Overlay approaches for moving object detection and tracking have recently received attention as a crucial field for computer science and computer vision research. Using pixel overlap and visual attributes, these techniques enable the recognition and tracking of objects in movies or video data. Two color and edge features for the suggested method are presented in this article. The suggested approach uses the SED algorithm, and since the edges have a lower volume than the entire image, the processing process will be faster with the reduction of information. The characteristic of color is the HSV (hue, saturation and value) histogram because it is close to human vision. However, because the margins tidy up the shapes in the human eye, they contain important information. These concerns lead to the conclusion that the histogram of gradient angles based on regional binary patterns is the edge feature of the suggested system. There are two justifications for employing local binary patterns. First, the principal edges are emphasized by using local binary patterns. Another point is that the image produced by this method displays the image's texture; in other words, the shape's feature is taken from the context of the texture, which is regarded as a type of combination of features. Several criteria were evaluated in order to assess the suggested approach for tracking images in comparison to related systems; the most significant of these are the precision, recall, and similarity criteria. In comparison to other works, the findings for precision have generally increased accuracy by 25%, recall by 17%, and similarity by 12%.**

*Keywords—Tracking; moving object detection; image processing; binary patterns; HSV histogram*

## I. INTRODUCTION

Today, object identification, particularly machine vision and pattern recognition, is one of computer sciences most significant and broad study domains. Even after an object's appearance has changed, the human brain is still able to instantly recognize and categorize many different types of items [1]. Different characteristics, such as changes in brightness, state, texture, shape, and object occlusion, affect how well the human visual system can identify things [2]. Additionally, the human brain has the capacity to extrapolate its findings from a collection of things and reliably recognize ones it hasn't yet seen [3]. Scientists working in the fields of machine vision and computer science have used the study of the human brain's cognitive capacity to recognize and draw inspiration from it to design and present a variety of object recognition systems [4]. In order to organize visual information, these findings are also used in related applications like picture concept recovery and image indexing [5]. Visual characteristics are the primary source of information used by conventional object recognition techniques to identify items in real-world photographs [6]. To a certain extent, visual characteristics, including color, form, texture, and picture edges, can compensate for changes in an object's appearance. Additionally, new methods have attempted to explain the interactions of objects in a scene or general statistical notions using conceptual features [7]. These methods for object identification applications increase recognition precision and clear up conflicts those traditional systems, with their reliance on visual features, experience [8]. There is a noticeable increase in image data globally, and that growth rate is accelerating daily. According to Information Trends, more than 1.1 trillion images were taken in 2016 with cameras and mobile devices [9]. The same forecast predicts that by 2020, this amount will have increased to $1.4 trillion. Many of these photographs are made available online or through cloud services. In 2014, prominent websites like Instagram and Facebook had daily photo uploads of more than 1.8 billion [10]. Beyond consumer electronics, there are cameras everywhere that take pictures for automation. Traffic cameras and moving cars are both watching the road. Robots need to be able to see in order to categorize objects and get rid of trash intelligently. Engineers, medical professionals, and explorers of space all employ imaging instruments. We need to have an understanding of this data's contents in order to manage it successfully. A wide range of image-related tasks benefits from automated content processing [11]. This requires computer systems to bridge the "semantic gap" between surface pixel information stored in image files and how people perceive analogous images. Computer vision is applicable in this area. Images can contain objects that can be automatically found and recognized. One of the core issues with computer vision is what is known as object detection. We'll demonstrate that convolutional neural networks now offer the best method for detecting objects [12]. Examining and putting to the test convolutional object identification techniques is the main goal of our research. The goal of computer vision is to derive useful information from the content of digital photographs or videos. It's just straightforward image processing, which entails fiddling with visual data down to the pixel level. Applications of computer vision include traffic automation, picture classification, visual identification, image retrieval, augmented reality, machine vision, and reconstruction of 3D scenes from 2D images [13]. Image tracking is one way to detect moving objects. An image tracker is a system that sequentially tracks preset items in a series of photographs [14]. In other words, the tracking process is the act of estimating the temporal and spatial changes of the object or, more generally, the states of

the target object during the video sequence based on measurements and observations. The target object may be specified by detection algorithms or manually [15]. Using data from earlier frames and additional data, such as the target's movement model or appearance attributes, the tracking system calculates and looks for the target in the current frame. An innovative technique for tracking images is given in this study. Color and edge features, the SED technique, and local binary patterns have all been utilized in image analysis to extract information from images and moving objects. The application of this technique highlights how closely color qualities resemble human sight and how crucial the information at the margins is. This approach can also aid in developing algorithms with increased processing speed and accuracy for picture recognition. In general, these developments can advance the science of picture tracking and enhance the functionality of systems for image analysis and recognition. The writers' contribution to this study can be summed up as follows:

- Find objects in the image and background dataset.

- Image tracking using color and edge features.

The remainder of the essay is structured as follows: Section II highlights earlier research on object detection using various image processing methods. Section III contains the suggested concept and approach. Section IV discusses the outcomes of the evaluation and simulation and Section V contains the conclusion and recommendations for future work.

## II. RELATED WORKS

The study gap that this research tries to solve is improving the efficiency and accuracy of moving object detection and tracking in computer vision and image processing. As mentioned in the introduction, to solve this gap, the proposed solution for tracking accuracy and detection combines color and edge features, uses SED algorithm and local binary patterns to increase detection and tracking of moving objects. The difficult task of identifying things in the image is one that numerous researchers are presently doing. The long-term objective of picture understanding is to recognize all objects in a general scene; however, this is still difficult due to factors like intra- and extra-class diversity, state and location, backdrop complexity, overlap, significant illumination variations, etc. Numerous publications published recently compared the effectiveness of various approaches' identification rates and mistake rates. However, a number of factors, including learning and execution times, the number of training samples, and the proportion of the mistake rate to the recognition rate are important when evaluating algorithms. The comparison is further complicated by the fact that researchers' definitions of recognition and error rate differ. The research in [16] proposes a new technique for employing a stereo camera to detect objects with many colors distributed unevenly in complicated backgrounds and then estimate the depth and form of the object. In this study, color saturation space is separated into fuzzy color histograms based on self-clustering in order to extract characteristics for object detection. A fuzzy color histogram is created for each window scan in a pyramid of graded images by adding the fuzzy degrees of all the pixels in each cluster. The right and left photos are initially segmented

using color space to identify the matched item region in the right image. The study in [17] provides an overview of current advances in the field of object recognition in remote-sensing photos. Many studies have been conducted to find things in aerial and satellite photos throughout the last few decades. They are separated into four primary groups in this article: machine learning-based approaches, knowledge-based methods, object identification methods based on object-based picture analysis, and methods based on template matching. This page explains the categorization of object recognition research. Depending on the format a user chooses, there are two additional types of matching methods: hard pattern matching and metamorphic pattern matching. In [18], a context-oriented salient Bayesian model is put out to address the problems of scale variance and detection ambiguity in small item identification. The sea is the object of this article's visual analysis. It is possible to understand that there is a link of reliance between the place and the scale at which things may occur by looking at the geometry of the camera in the image against the background of the sea and sky. The model described in this study is a universal model that may be applied to many contexts with various images to facilitate the object. The research in [19] presents a comprehensive review of the statistical learning-based representation of features in object recognition. This article compares the evaluation outcomes of object detection algorithms with various visual features and categorizes visual features based on differences in computations and visual attributes. Therefore, the objective of this review is to develop a thorough and complete plan for researchers. The portrayal of the influence of features is a concern when taking into account the demands of generic object recognition. To increase the representational strength of object recognition models, it is important to acquire extensive and powerful visual features. The display of comprehensive features can be effectively removed by combining various visual property aspects. An innovative component-based method for object detection on a two-dimensional image and its use as a visual landmark has been presented by researchers in [20]. Object recognition is a hybrid cryptographic system that makes it possible to keep track of the topology and use it to power the recognition procedure. As shown in the aforementioned study, it is challenging to separate the components of an item from a two-dimensional image; it is only logical for the image to represent either the upper or lower component. Determining the object and its representation from the existing image and the various numbers deduced from the pieces is the goal of this research. The study in [10] presents a brand-new energy function based on the autocorrelation function for active contour models, allowing for recognizing small objects against textured and chaotic backgrounds. To show the information of each area, the proposed method calculates picture characteristics for each pixel in the image domain using a combination of short-term autocorrelations. A novel energy function dubbed "normalized accumulated short-term autocorrelation" is introduced for the active contour based on the localized area using the collected features. Small items can be recognized in pictures with cluttered backgrounds and heterogeneous textures by decreasing this energy function. Researchers in [21] have presented a brand-new method for picture edge identification based on ACO. In the suggested

approach, coupled optimization techniques have been applied, which has aided in speeding up the process of solving optimization issues. In this method, artificial ants first produce a number of answers, the information from which is then useful for the genetic algorithm. These answers then serve as the initial population for the genetic algorithm, and the genetic algorithm then produces the subsequent population from these answers. A new edge identification technique for satellite pictures with low contrast has been proposed in another study [22]. It has been mentioned in this article that it is quite challenging to extract edges from satellite photos with low contrast, smoothness, and features. Therefore, the Sobel edge

detector performs preprocessing on the input image. Low-pass and high-pass filter operations are carried out on the normalized images after the input image has been normalized. The relaxation factor comes after the output of high-pass and low-pass filtering. Following this filtering process, the preprocessed image is subjected to the Sobel edge detection method for edge identification. By identifying the features that work best for identifying things in a picture, the structure of the object identification system can be reduced more successfully without the need to expand the training set, and a better outcome will likely be seen as a result. A comparison of earlier investigations is provided in Table I.

TABLE I. COMPARATIVE STUDY OF THE METHODS PRESENTED IN PREVIOUS STUDIES

| Simplicity | Area | proposed method | Application | Ref. |
|---|---|---|---|---|
| Simple and easy to implement | Stereo camera | Fuzzy color histograms | Spatial | [14] |
| Simple method | Optical remote sensing images | Review of object recognition methods | conversion | [15] |
| Simple method | Infrared images | An outstanding text-oriented Bayesian model | conversion | [16] |
| Simple method | Decomposing images into different areas | Wavelet method | Spatial | [17] |
| The simple and fast method | Digital images | learning-statistics | conversion | [18] |
| The simplest and most suitable for dark images | driving | Image segmentation, color composition and topology | Spatial | [19] |
| Simple method | Identifying small objects | Contour model | Spatial | [8] |
| Simple method | Moving Pictures | Creating and testing hypothesis and verification step | Spatial | [20] |
| It provides a better visual effect | Digital images | meta-heuristic algorithm | Spatial | [21] |
| It provides a better signal than noise | Satellite Images | High-pass and low-pass filtering | Spatial | [22] |

## III. PROPOSED METHOD

The proposed system has two techniques for accuracy and speed, which have been reviewed and put into practice. Two qualities of color and edge are taken into consideration in the suggested strategy. The provided technique uses the SED algorithm, and since the edges have a lower volume than the entire image, with the reduction of information, the processing process will be faster, from the HSV histogram's characteristic of color to its nearness to human perception. Because shapes are cleaned up by their edges in human vision, other edges carry important information. These concerns lead to the conclusion that the histogram of gradient angles based on regional binary patterns is the edge feature of the suggested system. There are two justifications for employing local binary patterns. First, the principal edges are emphasized by using local binary patterns. Another point is that the image produced by this method displays the image's texture; in other words, the shape's feature is taken from the context of the texture, which is regarded as a type of combination of features. The proposed algorithm's flowchart is shown in Fig. 1.

### A. Feature Extraction using SED Algorithm

The SED approach efficiently displays picture information and simultaneously extracts color and texture features. Five

structural formats are utilized to determine the texture perception from the original color image, separated into 72 colors in the HSV color space. A three-step process is employed to get the final descriptive image of the structural elements:

- With step 2, move the SED 2x2 from left to right and from top to bottom, starting at the reference point (0, 0).

- This value is saved if the structure's elements match the image's value (a match denotes that the value of the image in the related structure is equal).

- Then, the SED map is obtained, which has five $S_i(x,y)(1 \leq i \leq 5)$ structures and is distinguished by. When the components of the nondirectional representation structure are recognized, four additional structures in particular need to be found. Since there is no direction, every direction is feasible.

- The following equation, generated by combining five maps as in Eq. (1), illustrates the final SED map.

$$S(x,y) = \{(x,y) \mid S_1(x,y) \bigcup S_2(x,y) \\ \bigcup S_3(x,y) \bigcup S_4(x,y) \bigcup S_5(x,y)\} \tag{1}$$
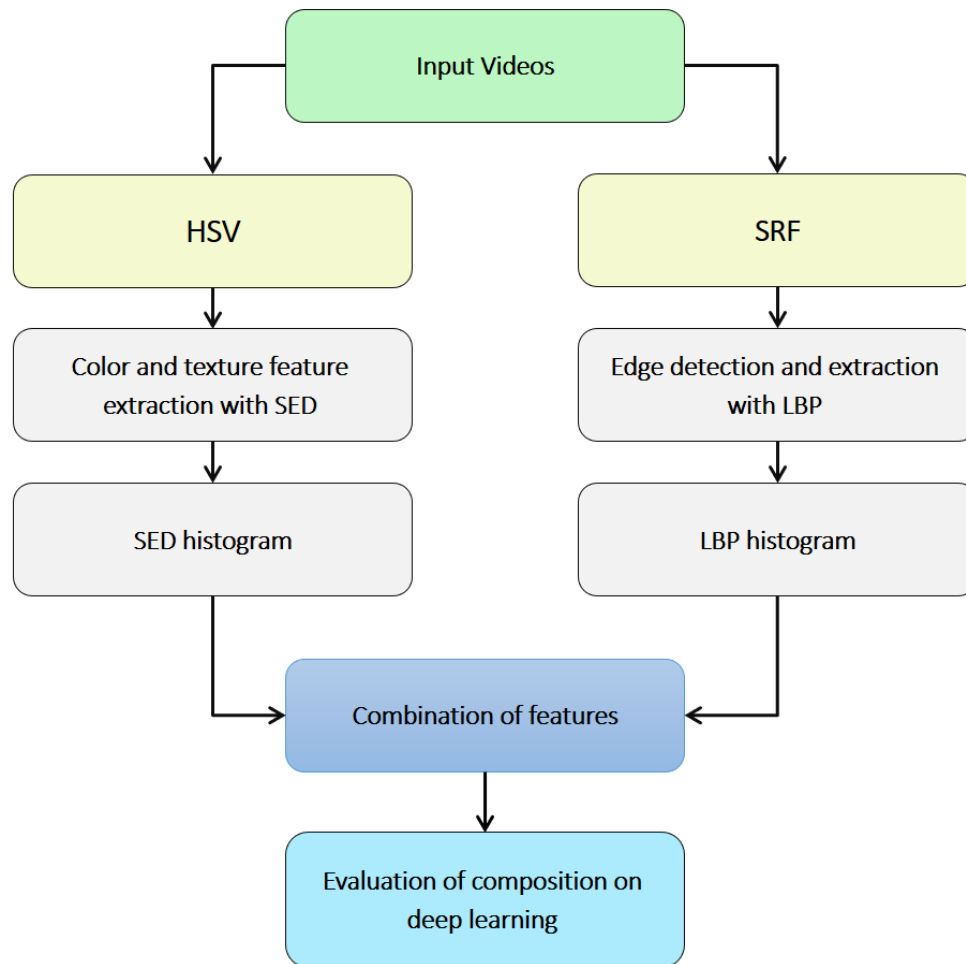
Fig. 1.   Block diagram of the proposed method.

*B. HSV Color Histogram*

The use of color histograms, one of the most significant picture-based recovery approaches, is the most used technique for recovering the color of an image. The image is provided by this histogram, which is produced as a cumulative distribution of the sub-distances connected to each pixel. Defining the color space is the first step in producing a color histogram. Generally speaking, the RGB color space is present in a number of picture formats, including BMP, GIF, etc. We will have fewer calculations if we choose this space, but the main issue is the non-uniformity from the perspective of perception. Because of this, HSV space has been substituted for RGB space in the proposed method. The following is an example of an HSV space benefit. Its suitability with how humans perceives color is due to the independence of the color type and brightness components, which allows us to assign superiority to any one of the components (see Fig. 2). Based on category (H) or wavelength, level of color saturation (S), and level of brightness (V), the dimensions of this space constitute color. Conical in shape, the aforementioned space contains:

- The wavelength of a color is defined in the range $[0, 2\pi]$, where red is at an angle of 0 degrees, green is at an angle of $2\pi/3$, and blue is at an angle of $4\pi/3$, the final

angle. The wavelength of color is equal to the angle of the color in the section of the cone circle.

- At an angle of $\pi 2$, it changes back to red once more.

- The central axis of the cone corresponds to the brightness of the color.

- The amount of color saturation varies depending on how far a given point on the circle is from the center axis; the closer a color is to the axis, the less concentrated it is, and the more it resembles a gray hue.

Because it is more stable than changes in the direction of photographing an item or scene, H is the primary component employed in retrieval systems. It is, nevertheless, extremely sensitive to variations in light. After this space, it is linearly quantized to create the color histogram. Because H space is more significant than other components, the other two components are quantized into four intervals each, but this component is quantized into 16 intervals. By counting the points positioned in each interval and normalizing them to the overall number of picture points, the color histogram of the image is created. A 256-dimensional vector is produced after indexing each image using the HSV color histogram feature.

## C. Texture Feature Extraction

The methods for texture-based recovery are based on the assessment of texture features in the images, such as texture contrast, roughness, texture direction, texture regularity or texture periodicity, and texture unpredictability.

In order to speed up processing, the input color photographs are converted to grayscale at this point. A Gaussian filter is then applied to the grayscale image to help remove any potential noise. Eq. (2) defines a Gaussian function as follows:

$$w(x,y) = \frac{1}{2\pi\sigma^2} e^{\frac{x^2+y^2}{2\sigma^2}} \qquad (2)$$

Then the image is averaged: Consider the noisy image g(x,y), which is obtained from adding noise n(x,y) with the original image f(x,y).

$$g(x,y) = f(x,y) + n(x,y) \qquad (3)$$

In this case, it can be easily shown with Eq. (4) that by averaging the noisy image of an object, a good approximation of the original image M can be obtained.

$$\ddot{g}(x,y) = \frac{1}{m}\sum_{i=1}^{m} g_i(x,y) \qquad (4)$$

Many edge detection algorithms use the first derivative of illumination, which means that we operate with the original data's illuminance gradient. With this knowledge, the peaks of the brightness gradient can be looked for in an image. The second derivative of brightness intensity, which is actually the rate of change of the brightness intensity gradient and is the best for detecting textures, is the basis for some other edge detection algorithms. As a result, a brightness gradient can be seen on one side of the line and its opposite gradient on the other. As a result, we can anticipate a fairly significant shift in the illumination's gradient in intensity at the site of a line. You can look for the transition of gradient change zeros in the results to discover bright textures. If I (x) is the light's intensity, then Eq. (5) [12] is as follows: To be able to extract texture features from photos is the aim. A multidimensional texture feature vector is believed to be the output of a color image, which is considered to be the input.

$$L(x,y) = \nabla^2 f(x,y) = \frac{\partial^2 f(x,y)}{\partial x^2} + \frac{\partial^2 f(x,y)}{\partial y^2} \qquad (5)$$
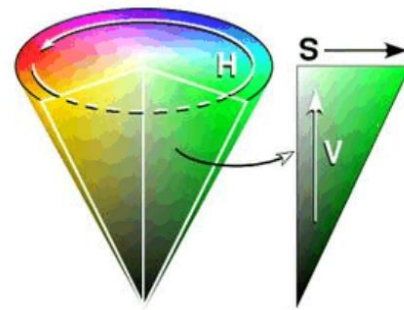


Fig. 2. HSV color space.

## D. Edge Extraction using Local Binary Patterns

As a potent image texture descriptor, the primary LBP operator was first introduced in [23]. This operator creates a binary number for each individual pixel using the nearby 3x3 pixel labels. The value of nearby pixels is used to threshold these labels. The value of the center pixel is found. In this approach, a label of 1 is placed for pixels whose values are more than or equal to the value of the central pixel, and a label of 0 is placed for pixels whose values are lower than the value of the central pixel. They start to form. Fig. 3 illustrates how this operator functions.

The LBP operator's 3x3 neighborhood base is too small, which prevents it from dominating large-scale images. This operator, which is shown as LBPP, R, and can produce a maximum of p2 different values according to p2 of the binary pattern produced by P pixels on the neighborhood radius of R, was later proposed for this purpose with an extension of neighborhood size in [24]. Fig. 4 illustrates how to choose adjacent pixels in this kind of arrangement. It displays three different local binary radii.

Fig. 5 illustrates the unique significance and notion attached to the patterns created by LBP. This figure shows that LBP is capable of detecting points, edges in various directions, smooth areas, line ends, etc. The histogram of these labels is calculated after assigning LBP labels to pixels in order to create image texture. Numerous researches have concentrated on the use of LBP because of its ease of calculation and acceptable findings, and in this regard, new and varied variants of it have been suggested for usage in various circumstances [25].



Binary: 01111100  decimal: 124
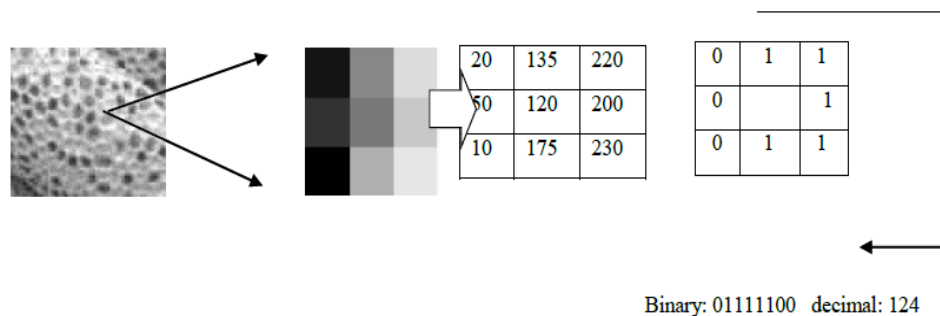
Fig. 3. How to calculate the LBP operator.
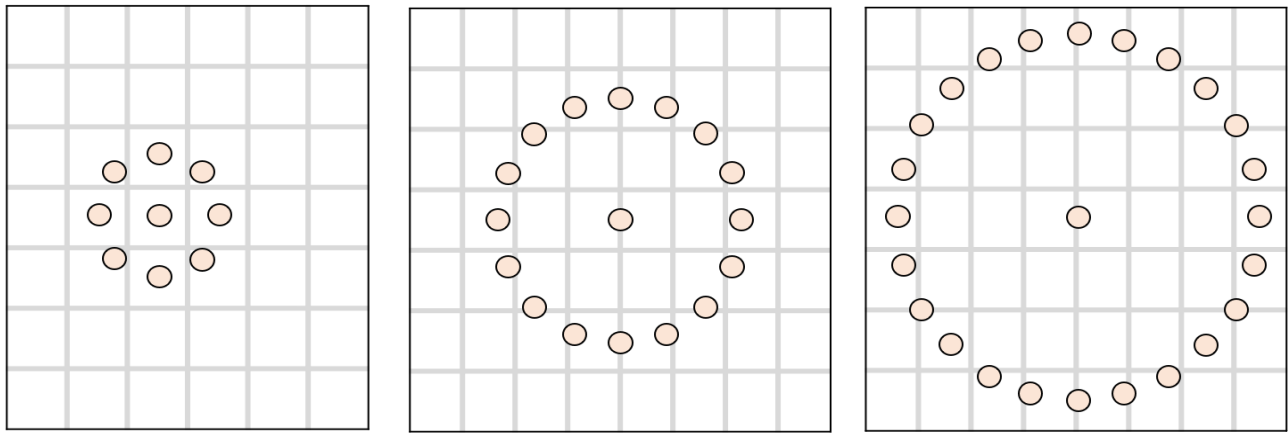
Fig. 4. LBP operator with different radii and number of neighborhoods.



**Spot**  **Spot/flat**  **Line end**  **Edge**  **Corner**
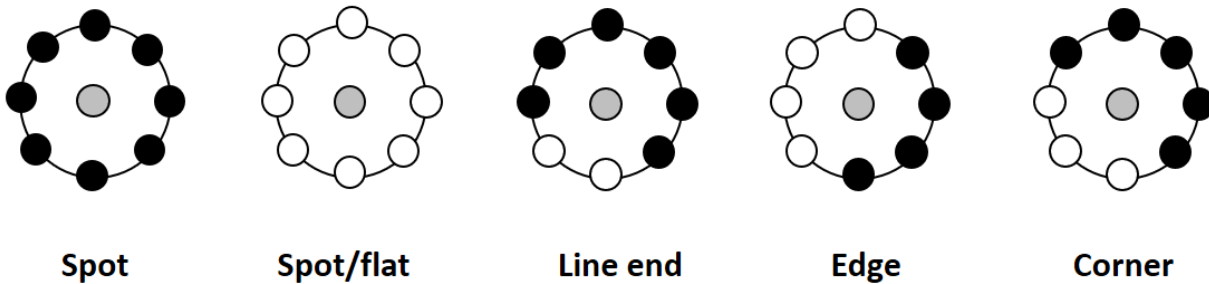
Fig. 5. Examples of the concept of patterns produced in LBP, the white and black circles represent the number one and zero, respectively.

After the pixels are labeled by the LBP operator, a histogram of the produced patterns is defined as Eq. (6).

$$Hi \sum x,yi(fi\ (x,y)=i),\quad i=1,\ldots,n-1 \qquad (6)$$

where n is the number of patterns produced by the LBP operator and the function I is defined as Eq. (7).

$$I\ (A) = \begin{cases} 1\ A\ is\ True \\ 0\ A\ is\ False \end{cases} \qquad (7)$$

Local binary patterns with radii of 1 and 8 neighbors are considered in the suggested strategy. Finding and obtaining most systems utilize the closest neighbor search to look for and locate related photos when searching for photographs. For each query image, the KNN classification algorithm examines the set of training images for related images. If the system employs n features, it will treat the images as vectors in the following n-dimensional space. K seeks the neighbor of the query image from the training photos, and among these neighbors, the class label that is in the majority is used as the category label of this image so that each image in this space is comparable to a point. The question foretells Finding and calculating a criterion for the similarity or distance between attributes in the data is the first task to be completed using k-NN. One of the challenges of this method is calculating the distance between the photos; if the distance between the images is not accurately determined, the algorithm will not function properly.

*E. Combinations of Features*

After the feature extraction phase, it should be decided how to combine them. There are other ways to combine the features, but the simplest is to arrange them in a row to create a single matrix and then use other photos to calculate distance. This work has a number of issues. The majority of the features have different sizes, so when combined, the feature with the larger size will have a greater effect. However, larger size does not always imply higher efficiency or greater importance. It is also impossible to compare the effects of some features according to performance. It excels in other aspects. A more effective solution: weighting and distance calculation are done separately for each feature. There are two features here with the designations F1 and F2, respectively. The letters w1 and w2, respectively, designate the weights assigned to each attribute. In this manner, the effect of the features changes depending on the coefficient that w12 accepts, and the best weight can be attained with various variations. The edge feature's weight in the suggested technique is 0.4, while the color feature's weight is 0.6.

*F. Detection Criteria with Deep Learning*

Auto-indicators are one of the techniques of deep learning. An advanced form of artificial neural network called an auto-encoder is used to discover the best code. With this technique, you train an auto-encoder to reconstruct its input X rather than train the network to predict the target value Y along the input X. As a result, the output vectors will match the input vector's dimensions. Fig. 6 shows the general operation of an auto-encoder. The auto-encoder is improved during training by reducing the reconstruction error. It learned the appropriate code for the same feature [26].

The detection of moving targets in overlapping scenes will be carried out in this study with the use of an auto-encoder and a deep-learning technique. Fig. 7 illustrates the general

workflow of the method, which includes the following steps: (1) receiving the image; (2) filtering and enhancing the image; (3) modeling the background; (4) choosing one of the moving images; (5) image training using deep learning; (6) target tracking with the aid of an auto-encoder and deep learning; (7) feature extraction; and (8) classification.
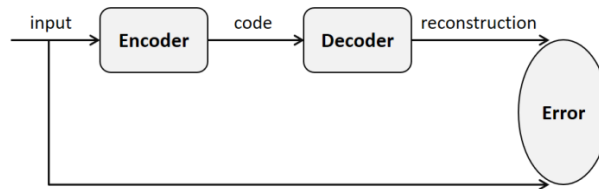


Fig. 6.   General process of an auto-encoder.
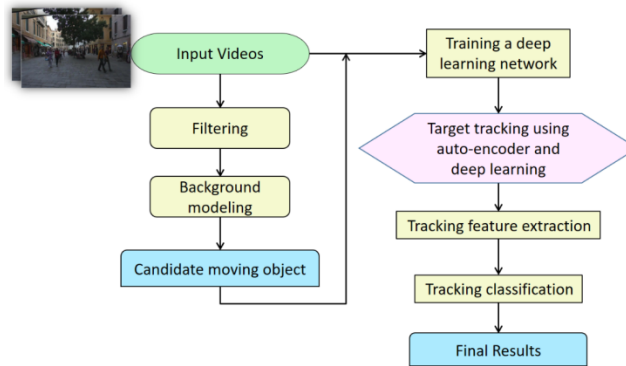


Fig. 7.   Steps to perform work to detect moving targets.

The training photos, which contain the target images and their labels, are first fed into the deep learning algorithm, as can be seen in the flowchart of how the suggested approach is implemented. After training the network, it will be able to track the target in the test images. Higher-accuracy architecture will be selected while developing the algorithm's architecture [27]. The incoming moving images are first given a Gaussian filter, which suppresses some random noises that frequently emerge near object borders. In this step, several redundant and erroneous objects are eliminated from the results of the object detection process. A non-parametric background modeling approach [27, 28] is chosen after choosing the moving item in the second phase to produce the initial detection results of the moving object with high recall but low precision. Target tracking is recovered in the third stage by utilizing an auto-encoder and deep learning techniques that are derivations of a hybrid method. Then, characteristics are taken for each detector and applied to distinguish between actual moving targets and fake ones. The last stage can be utilized as a constraint to accurately inspect moving objects and obtain high accuracy and recall by combining the autoencoder and deep learning techniques.

## IV. EVALUATION AND SIMULATION

Image tracking of moving targets in video images is particularly important in machine vision and widely used in robotics and automatic video surveillance. The importance of this issue lies in making the systems smarter and improving the accuracy and speed of the machine's decision-making by receiving visual information. In this research, the aim is to investigate image tracking algorithms based on deep learning methods and provide a new tracking method based on deep learning for more accurate target tracking.

### A. Data Sets

The dataset available at https://motchallenge.net will be used as the dataset of this research, which includes consecutive images of targets in different lighting conditions and with different overlaps. Fig. 8 shows an example of images from the dataset.

### B. Comparison Methods

Deep learning methods and convolutional networks have had good results in tracking moving targets. For example, in study [10], a method based on convolutional neural networks is presented in study [10] to track targets in crowded and noisy environments with low contrast, provided that it is able to track moving targets using color. In research [16], a method based on deep learning to track targets is presented. In this method, first, the features of the target are learned by a very deep network, then these features are sent to the support vector machine, and finally, the support vector machine can identify the goals.

### C. Precision Criteria

This criterion shows the type of accuracy; the higher it is, the better; this criterion shows the accuracy of the proposed method for positive cases and how accurate it was in identifying positive cases. This criterion is one of the most important accuracy criteria in detection algorithms and is calculated from Eq. (8).

$$Precision = \frac{TP}{TP+FP} \qquad (8)$$

Fig. 8. An example of images from the dataset.

In this regard, TP is the number of data that are correctly recognized as positive, and FP is the number of data that is falsely recognized as positive. The simulation result based on the above criterion is shown in Fig. 9.

The simulation result shows that the proposed method performs better in this criterion and has been able to perform image recovery operations with higher accuracy. In Table II, the result of the Precision criterion can be seen in different simulation situations.

### D. Recall Criteria

The next measure of accuracy is the Recall measure; this criterion checks the accuracy of the method in identifying negative states, that is, how accurate the method was in identifying negative states, which is calculated through Eq. (9).

$$Recall = \frac{TP}{TP+FN} \quad (9)$$

In this regard, TP is the number of data that are correctly recognized as positive, and FN is the number of data that is falsely recognized as negative. The recall criterion is objectified according to the above scenario, and the result can be seen in Fig. 10.

The method presented in this research has a better performance in this criterion according to the investigation carried out by the simulator; in Table III, the result of this criterion can be seen in different simulation situations.

### E. Accuracy Criteria

The next evaluation criterion is the accuracy criterion. This important criterion is calculated based on Eq. (10).

$$Accuracy = \frac{TP+TN}{TP+TN+FP+FN} \quad (10)$$

In the above relation, the TP parameter represents the number of images that have been correctly retrieved; and the FP parameter also indicates the number of images that have a negative effect and the proposed models have predicted that sample negatively. FN represents the number of samples that have a negative effect on image recovery, and the proposed model has positively predicted these samples. TN represents the number of samples that have had positive effects on recovery, and the proposed method also predicts them to be negative in the recovery process; therefore, with the help of relation (10), the level of accuracy can be seen in Fig. 11.
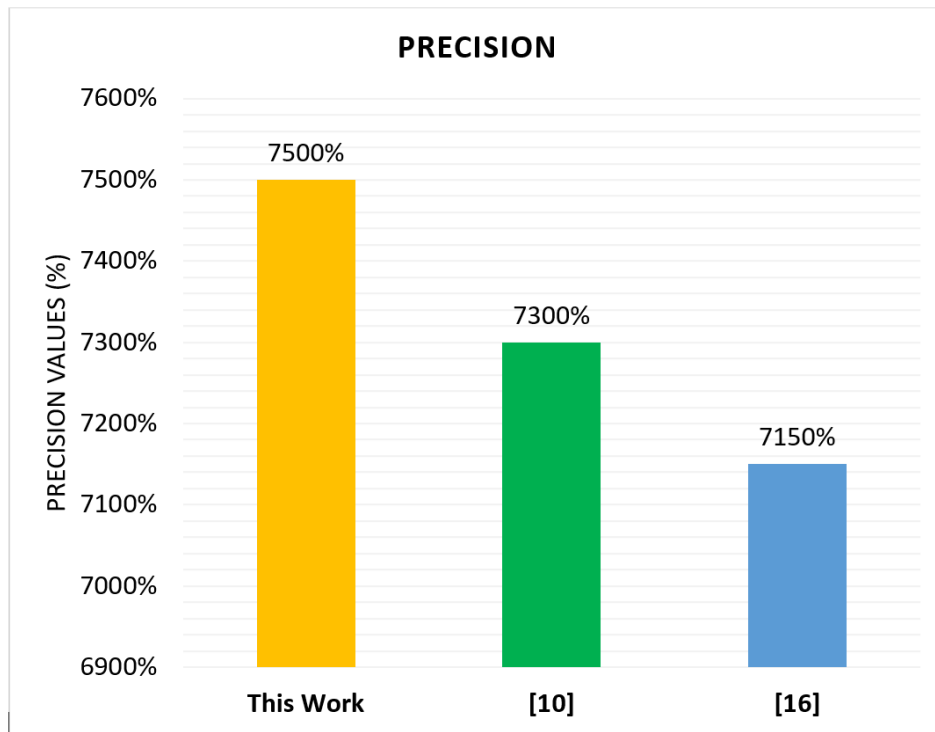
Fig. 9.  Comparison of precision criteria.

TABLE II.      COMPARISON OF PRECISION CRITERIA IN DIFFERENT SIMULATION SITUATIONS

|  | precision values | | | | |
|---|---|---|---|---|---|
|  | *250* | *500* | *750* | *1000* | *Average* |
| This Work | 78.00% | 71.00% | 74.00% | 77.00% | 75.00% |
| [10] | 70.00% | 73.00% | 74.00% | 75.00% | 73.00% |
| [16] | 69.00% | 71.00% | 72.00% | 74.00% | 71.50% |
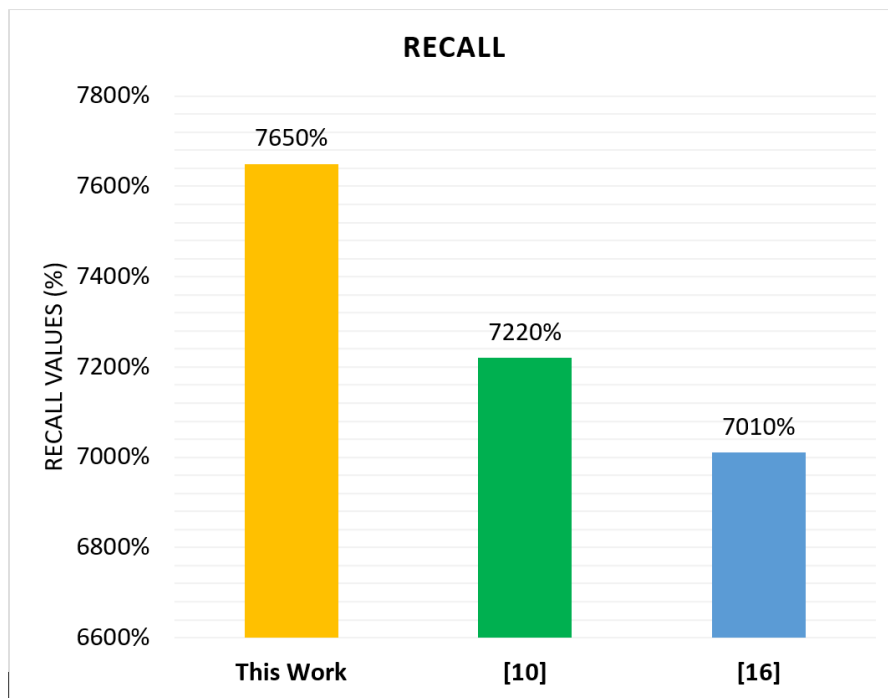


Fig. 10.  Recall criterion.

TABLE III.    COMPARISON OF RECALL CRITERIA IN DIFFERENT SIMULATION SITUATIONS

| | Recall values | | | | |
|---|---|---|---|---|---|
| | *250* | *500* | *750* | *1000* | *Average* |
| This Work | 72.00% | 75.00% | 79.00% | 83.00% | 77.25% |
| [10] | 68.00% | 70.00% | 73.00% | 79.00% | 72.50% |
| [16] | 65.00% | 68.00% | 72.00% | 77.00% | 70.50% |
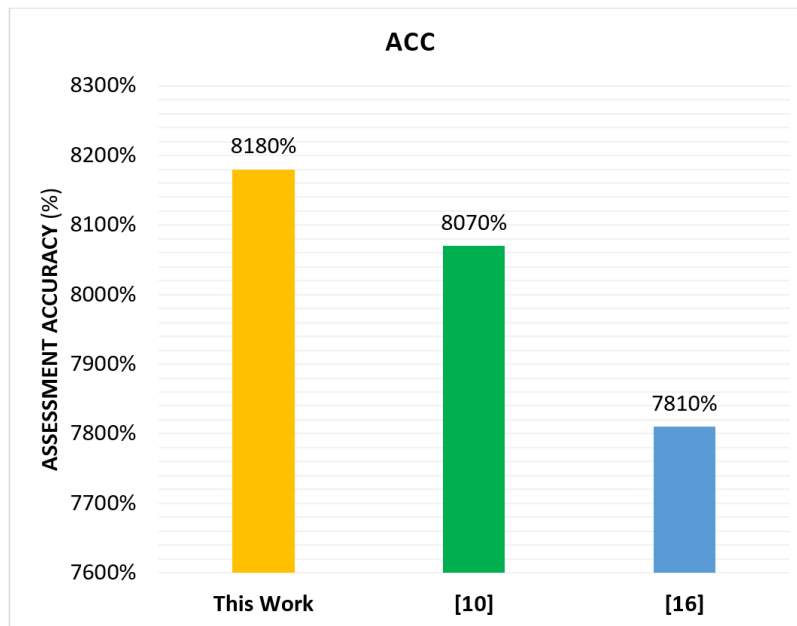


Fig. 11.  Comparison of the accuracy of the proposed method with the other two methods.

TABLE IV.    COMPARISON OF ACCURACY CRITERIA IN DIFFERENT SIMULATION SITUATIONS

| | accuracy values | | | | |
|---|---|---|---|---|---|
| | *250* | *500* | *750* | *1000* | *Average* |
| This Work | 84.00% | 82.00% | 81.00% | 80.00% | 81.75% |
| [10] | 82.00% | 82.00% | 80.00% | 79.00% | 80.75% |
| [16] | 80.00% | 81.00% | 79.00% | 78.00% | 79.50% |

According to the results obtained from Fig. 11, the proposed method has acceptable performance and has performed better than other methods. In Table IV, the result of this criterion can be seen in different simulation situations.

*F. False Positive Rate (FPR) Criteria*

The next evaluation is the false positive rate (FPR) criterion; this criterion checks how many percent of the images the system has retrieved incorrectly; the lower this criterion is, the better. To evaluate this criterion, we performed the simulation in four stages, and the average result for all simulation models can be seen in Fig. 12. In Table V, the result of this criterion can be seen in different simulation situations.

*G. FRR Criteria*

The next evaluation is the false negative rate measure. This measure shows how many percent of the correct images the detection system misidentifies; it can be seen in Fig. 13.

TABLE V.    COMPARISON OF AVERAGE FPR CRITERIA IN DIFFERENT SIMULATION SITUATIONS

| | FPR values | | | | |
|---|---|---|---|---|---|
| | *250* | *500* | *750* | *1000* | *Average* |
| This Work | 6.00% | 8.00% | 12.00% | 17.00% | 10.75% |
| [10] | 7.00% | 12.00% | 17.00% | 26.00% | 15.50% |
| [16] | 8.00% | 13.50% | 19.00% | 26.00% | 16.63% |
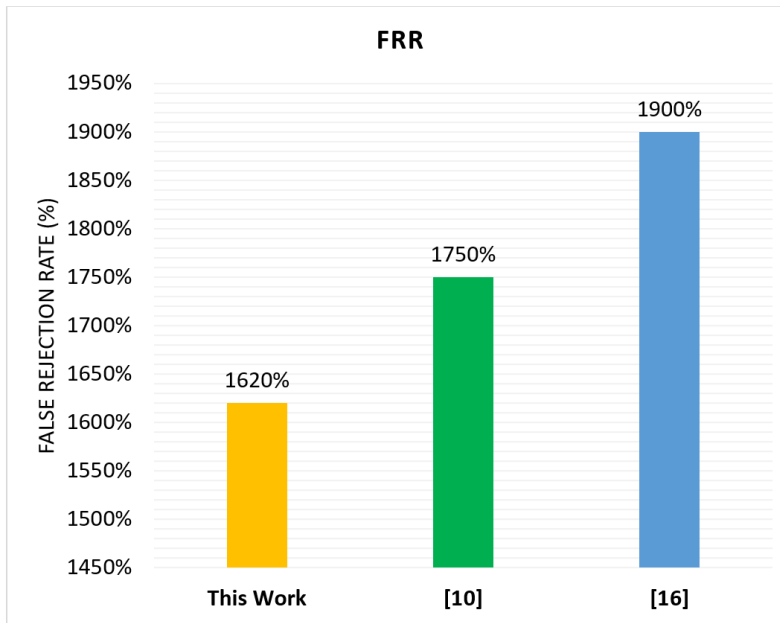
Fig. 12. Average FPR criterion.
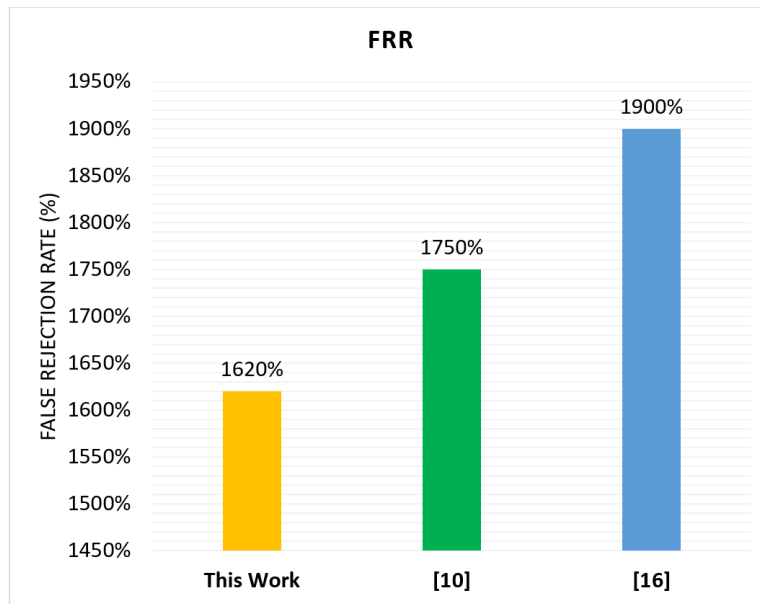


Fig. 13. The result of the FRR comparison.

TABLE VI. COMPARISON OF AVERAGE FRR CRITERIA IN DIFFERENT SIMULATION SITUATIONS

|  | FRR values | | | | |
|---|---|---|---|---|---|
|  | *250* | *500* | *750* | *1000* | *Average* |
| This Work | 6.00% | 13.00% | 19.00% | 27.00% | 16.25% |
| [10] | 7.00% | 15.00% | 19.00% | 29.00% | 17.50% |
| [16] | 7.00% | 16.00% | 21.00% | 32.00% | 19.00% |

In this simulation criterion, it shows that the proposed method has little improvement compared to the other method. In Table VI, the result of this criterion can be seen in different simulation situations.

*H. Similarity Criterion*

In this part, the proposed method is evaluated based on the similarity criterion in image recognition; in the scenario of this criterion, the degree of similarity of the output images of the program is evaluated, and the result is shown in Fig. 14.
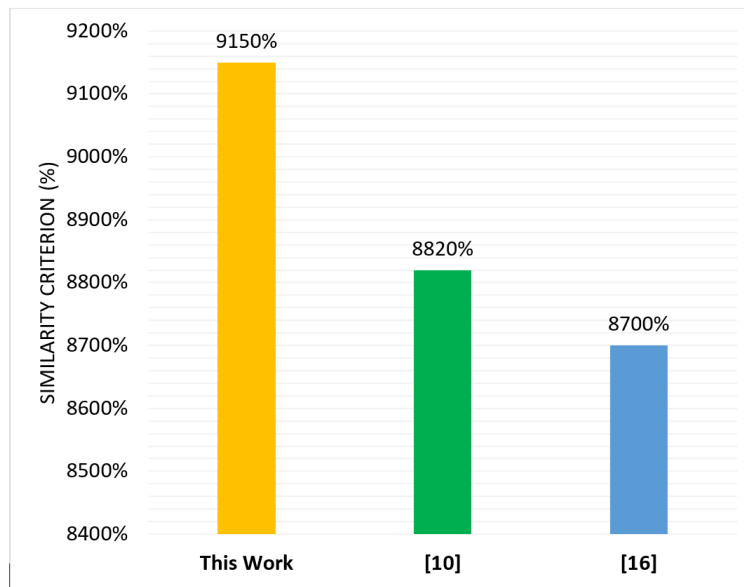
Fig. 14. Comparison of similarity criteria.

As the simulation results in Fig. 14 show, the proposed method performs better than the other two methods. The numerical result of this criterion in several stages of evaluation can be seen in Table VII.

*I. LTDR Criteria*

- LTDR (Label Tracking Detection Rate) criterion will be used to evaluate the presented algorithm. The LTDR measure determines the rate of assigning unique correct labels to targets and is defined as Eq. (11).

$$LTDR = \frac{1}{L}\sum_{i=o}^{L-1}\frac{TPM_i}{OAF_i} \qquad (11)$$

In this regard, L is the total number of targets to be labeled; $TPM_i$ is the number of frames in which the $i_{th}$ target is

correctly labeled, and $OAF_i$ is the total number of frames in which the i-th target is present. The value of this criterion is between zero and one, and the closer it is to one, it means that the detection algorithm has worked correctly. The evaluation result for this criterion can be seen in Fig. 15.

- Finally, Table VIII provides a summary of the accuracy ratings for this study. Higher recall, accuracy, and F-score have been attained using deep learning than with motion-based detection alone. These findings demonstrate how misdiagnosis brought on by inaccurate motion estimation can be supplemented by appearance information. Additionally, with a classification accuracy of over 96%, the deep learning approach may fully utilize the manually labeled training dataset.

TABLE VII. COMPARISON OF THE AVERAGE SIMILARITY CRITERION IN DIFFERENT SIMULATION SITUATIONS

| | similarity values | | | | |
|---|---|---|---|---|---|
| | *250* | *500* | *750* | *1000* | *Average* |
| This Work | 88.00% | 90.00% | 93.00% | 95.00% | 91.50% |
| [10] | 86.00% | 87.00% | 89.00% | 91.00% | 88.25% |
| [16] | 84.00% | 85.00% | 89.00% | 90.00% | 87.00% |

TABLE VIII. ACCURACY DETECTION BASED ON EVALUATION CRITERIA

| | Using only the difference in motion | Deep learning by the appearance |
|---|---|---|
| Accuracy | 0.854 ±0.12 | 0.914 ±0.02 |
| Recall | 0.752 ±0.14 | 0.769 ±0.06 |
| Precision | 0.609 ±0.10 | 0.664 ±0.10 |
| False Positive Rate | 0.781 ±0.09 | 0.813 ±0.08 |
| false rejection rate | 0.631 ±0.14 | 0.719 ±0.11 |
| Similarity criterion | 0.824 ±0.10 | 0.878 ±0.07 |
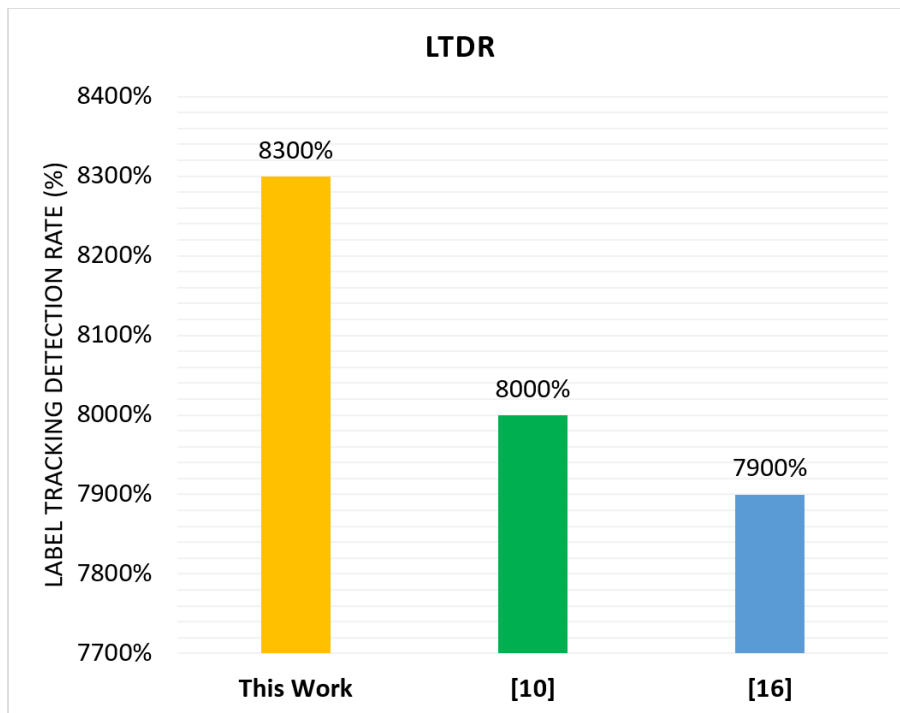
Fig. 15. LTDR criterion check.

In the continuation of this section, the studies related to the problems ahead and the goals of this research are as follows. Object tracking in computer vision, feature extraction and deep learning and convolutional neural networks were among the problems that were addressed in this research. Also, this article discusses the practical applications of object tracking in fields such as industrial, military and urban management. It highlights the importance of tracking moving objects in various scenarios including road control. The goals achieved in this research are: improvement in managing challenging situations, prediction of pattern change, efficiency and real-time processing and integration with autonomous systems. In summary, this research provides insights into the development and evaluation of a method for detecting and provides object tracking. This highlights the importance of accurate tracking in various applications and suggests potential directions for future research to improve the performance and applicability of the method in real-world scenarios.

## V. CONCLUSION

A modern civilization needs an intelligent system to control its many management systems. The object tracking system is one of the crucial tools that are employed in the field of operational control in many locations, which makes the job of this field and its authorities very difficult. This goes back to the macro-policies of society in the field of social welfare. Using cutting-edge image processing methods, the technology described in this article can accurately and affordably detect moving objects and track them. In fact, the technique described in this study for detecting moving things, such as cars and items, is quicker and more accurate than the earlier methods. It has been demonstrated that the suggested moving object tracking system, combined with the background subtraction algorithm, noise removal, filtering, and bubble routing, enables full automation when evaluating and identifying the moving item in the photos. More crucially, our system meets the standards established by decision-making bodies for road control for accuracy in detecting moving objects in road photographs.

In comparison to the tested samples, the test results show that the suggested method produces accurate and extremely dependable findings. The research's most significant applications largely concentrated on the precise position recognition of moving objects on photographs and their tracking using morphological analysis and bubble routing. Cameras should be positioned higher than the road surface in order to identify and track items like vehicles, but for all other uses, this is essentially unnecessary. Using a precise backdrop selection and processing each frame separately, this system accurately recovered pictures of moving objects. The wide applications of tracking moving objects are primarily in industrial, military, and urban management places, which can be, for example, the paths where moving objects are passing more frequently. As a result, according to these parameters, the proposed method can show different performances in different conditions. They even described the kinds of moving things in various photographs. Although the present study provides valuable insights into object detection and tracking, however, it has limitations including lack of real-world deployment, assumption of fixed cameras, performance on large-scale datasets, and limited discussion of handling. It is wrong to generalize to other types of objects.

Future research will focus on analyzing various visual patterns, such as grids, parallel lines, and dot matrices. Additionally, the moving object is more likely to shake since

the surface of the location where the video clip is captured may be uneven and bumpy. This shaking may move from left to right or up and down. As a result, the camera will record photos of the moving object in the route that is rotated and warped. Therefore, in order to be able to estimate and predict pattern change, robust and effective algorithms must be constructed in order to preserve the course of the pattern across successive frames. This is necessary to manage the change in the movement pattern of the valve that results from a natural impulse. The effectiveness and output of this algorithm can then be used to provide a more thorough description of the object's change in shape and pattern of movement.

## REFERENCES

[1] A. Mitrokhin, C. Fermüller, C. Parameshwara, and Y. Aloimonos, "Event-based moving object detection and tracking," in 2018 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), IEEE, 2018, pp. 1–9.

[2] S. Mane and S. Mangale, "Moving object detection and tracking using convolutional neural networks," in 2018 second international conference on intelligent computing and control systems (ICICCS), IEEE, 2018, pp. 1809–1813.

[3] P. K. Mishra and G. P. Saroha, "A study on video surveillance system for object detection and tracking," in 2016 3rd International Conference on Computing for Sustainable Global Development (INDIACom), IEEE, 2016, pp. 221–226.

[4] R. Verma, "A review of object detection and tracking methods," International Journal of Advance Engineering and Research Development, vol. 4, no. 10, pp. 569–578, 2017.

[5] S. R. Balaji and S. Karthikeyan, "A survey on moving object tracking using image processing," in 2017 11th international conference on intelligent systems and control (ISCO), IEEE, 2017, pp. 469–474.

[6] D. H. Ye, J. Li, Q. Chen, J. Wachs, and C. Bouman, "Deep learning for moving object detection and tracking from a single camera in unmanned aerial vehicles (UAVs)," Electronic Imaging, vol. 2018, no. 10, pp. 461–466, 2018.

[7] A. Keivani, J.-R. Tapamo, and F. Ghayoor, "Motion-based moving object detection and tracking using automatic K-means," in 2017 IEEE AFRICON, IEEE, 2017, pp. 32–37.

[8] Y. Ma, J. Anderson, S. Crouch, and J. Shan, "Moving object detection and tracking with doppler LiDAR," Remote Sens (Basel), vol. 11, no. 10, p. 1154, 2019.

[9] Cao, Y., Xu, N., Wang, H., Zhao, X., & Ahmad, A. M. (2023). Neural networks-based adaptive tracking control for full-state constrained switched nonlinear systems with periodic disturbances and actuator saturation. International Journal of Systems Science, 1-16.

[10] Wang, T., Zhang, L., Xu, N., & Alharbi, K. H. (2023). Adaptive critic learning for approximate optimal event-triggered tracking control of nonlinear systems with prescribed performances. International Journal of Control, 1-15.

[11] Trik, M., Molk, A. M. N. G., Ghasemi, F., & Pouryeganeh, P. (2022). A hybrid selection strategy based on traffic analysis for improving performance in networks on chip. Journal of Sensors, 2022.

[12] Trick, M., & Boukani, B. (2014). Placement algorithms and logic on logic (LOL) 3D integration. Journal of mathematics and computer science, 8(2), 128-136.

[13] Yue, S., Niu, B., Wang, H., Zhang, L., & Ahmad, A. M. (2023). Hierarchical sliding mode-based adaptive fuzzy control for uncertain switched under-actuated nonlinear systems with input saturation and dead-zone. Robotic Intelligence and Automation.

[14] Khezri, E., Zeinali, E., & Sargolzaey, H. (2022). A novel highway routing protocol in vehicular ad hoc networks using VMaSC-LTE and DBA-MAC protocols. Wireless Communications and Mobile Computing, 2022.

[15] Zhao, H., Wang, H., Xu, N., Zhao, X., & Sharaf, S. (2023). Fuzzy approximation-based optimal consensus control for nonlinear multiagent systems via adaptive dynamic programming. Neurocomputing, 553, 126529.

[16] M. Samiei, A. Hassani, S. Sarspy, I. E. Komari, M. Trik, and F. Hassanpour, "Classification of skin cancer stages using a AHP fuzzy technique within the context of big data healthcare," J Cancer Res Clin Oncol, pp. 1–15, 2023.

[17] J. Sun, Y. Zhang, and M. Trik, "PBPHS: a profile-based predictive handover strategy for 5G networks," Cybern Syst, pp. 1–22, 2022.

[18] M. Trik, H. Akhavan, A. M. Bidgoli, A. M. N. G. Molk, H. Vashani, and S. P. Mozaffari, "A new adaptive selection strategy for reducing latency in networks on chip," Integration, vol. 89, pp. 9–24, 2023.

[19] Khezri, E., Zeinali, E., & Sargolzaey, H. (2023). SGHRP: Secure Greedy Highway Routing Protocol with authentication and increased privacy in vehicular ad hoc networks. Plos one, 18(4), e0282031.

[20] M. G. Nayagam, K. Ramar, K. Venkatesh, and S. P. Raja, "Moving Object Detection and Tracking Algorithm Using Hybrid Decomposition Parallel Processing.," Intelligent Automation & Soft Computing, vol. 33, no. 3, 2022.

[21] Wang, Z., Jin, Z., Yang, Z., Zhao, W., & Trik, M. (2023). Increasing efficiency for routing in internet of things using Binary Gray Wolf Optimization and fuzzy logic. Journal of King Saud University-Computer and Information Sciences, 35(9), 101732.

[22] Khezri, E., & Zeinali, E. (2021). A review on highway routing protocols in vehicular ad hoc networks. SN Computer Science, 2, 1-22.

[23] Z. Bai, G. Wu, X. Qi, Y. Liu, K. Oguchi, and M. J. Barth, "Infrastructure-based object detection and tracking for cooperative driving automation: A survey," in 2022 IEEE Intelligent Vehicles Symposium (IV), IEEE, 2022, pp. 1366–1373.

[24] Cao, C., Wang, J., Kwok, D., Cui, F., Zhang, Z., Zhao, D., ... & Zou, Q. (2022). webTWAS: a resource for disease candidate susceptibility genes identified by transcriptome-wide association study. Nucleic acids research, 50(D1), D1123-D1130.

[25] Y. Guo et al., "The First Challenge on Moving Object Detection and Tracking in Satellite Videos: Methods and Results," in 2022 26th International Conference on Pattern Recognition (ICPR), IEEE, 2022, pp. 4981–4988.

[26] Zhang, H., Zou, Q., Ju, Y., Song, C., & Chen, D. (2022). Distance-based support vector machine to predict DNA N6-methyladenine modification. Current Bioinformatics, 17(5), 473-482.

[27] Z. Zhang, D. Cheng, X. Zhu, S. Lin, and J. Dai, "Integrated object detection and tracking with tracklet-conditioned detection," arXiv preprint arXiv:1811.11167, 2018.

[28] M. Zohaib, M. Ahsan, M. Khan, and J. Iqbal, "A featureless approach for object detection and tracking in dynamic environments," PLoS One, vol. 18, no. 1, p. e0280476, 2023.

# Exploring the Utilization of Program Semantics in Extreme Code Summarization: An Experimental Study Based on Acceptability Evaluation

Jiuli Li, Yan Liu[*]

School of Software Engineering, Tongji University, Shanghai, China

*Abstract*—With the rise of deep learning methods, neural network architecture adopted from neural machine translation has been widely studied in code summarization by learning the sequential content of code. Given the inherent nature of programming languages, learning the representation of source code from the parsed structural information is also a typical way for constructing code summarization models. Recent studies show that the overall performance of the neural models for code summarization can be improved by utilizing sequential and structural information in a hybrid manner. However, both of these two kinds of information fed to the neural models for code summarization fail to embrace the semantics of source code snippets in an explicit way. Is it really a good way to just leave the semantics as hidden things in the source code and have the neural models capture whatever they can get? To observe the utilization of program semantics in automatic code summarization, we conducted an experimental study by analyzing the acceptability of the extreme code summaries generated from neural models. To make the models aligned in the same context for this experimental study and to focus on the observation of the semantics, we re-implement the neural models from three selected studies as extreme code summarization solutions. After an intuitive observation and exploration of the generated summaries with the models trained from a Java dataset, we identify five acceptability aspects: (1) function name format; (2) function naming style; (3) semantic level similarity; (4) the differences in hitting rate of representative words; and (5) the correlation between extreme code summaries with function body. Based on the false negative and false positive phenomena in the results, ablation experiments have shown that the use of program semantics has a positive effect on generating high-quality abstracts in neural models. Our work proves the potential of utilizing the program semantics explicitly in code summarization, and the possible directions are also indicated.

*Keywords*—*Extreme code summarization; program semantics utilization; acceptability analysis of code summary*

## I. INTRODUCTION

The task of code summarization refers to the automatically creating readable summaries describing the function of the given code snippets, and identify the roles and responsibilities of software units [1]. A good summary can help developers understand, reuse and maintain code more easily, and greatly improve production efficiency. However, problems exist in code summaries, including missing information, errors, and outdated comments. Human-written summaries also require professional domain knowledge, making the entire process time-consuming. Hence, machine-generated summaries are gaining popularity, with their effectiveness acknowledged in many studies.

The majority of automatic code summarization algorithms rely on techniques such as information retrieval, stereotype identification, machine learning and artificial neural network, and natural language processing [2] [3]. Among them, deep learning techniques have demonstrated the benefits of modeling programs recently [4] [5]. Specifically, guided by neural machine translation, early code summarization models focus on the sequential content of code [6]. Yet, leading approaches have recognized the significance of integrating structural information derived from Abstract Syntax Trees (ASTs).

However, both traditional and deep learning techniques have limitations in generating natural language summaries. Traditional approaches struggle with extracting keywords when identifiers and methods are poorly named, and proper summaries cannot be generated if similar code snippets are absent. Moreover, the majority of deep learning-based approaches treat the source code as plain text, resulting in the omission of crucial information, such as naming conventions for identifiers and usage patterns of application programming interfaces [7] [8]. Since sequences of tokens parsed from AST are typically fed into the sequence-to-sequence framework, this approach may fail to capture long dependencies between code tokens [9]. These limitations may lead to the underutilization of program semantics at both the code text level and structural level, as evaluated using the acceptability of generated code summaries. However, there are currently no systematic studies to address this issue. To assess the acceptability of code summaries generated by neural models, we selected representative models from various categories for extreme code summarization tasks, and intend to get insights from the experimental results. The main contributions of our study are as follows:

- To explore the acceptability of the code summaries generated from neural models, we re-implement the neural models from three selected studies for extreme code summarization. Following an intuitive observation of the generated summaries, we proposed five acceptability aspects for further analysis.

- To identify which limitations of the selected models aggravate to the lower acceptability, we conducted a comprehensive analysis, focusing on the misjudgment in generated summaries. We found that false negatives in extreme code summaries can be attributed to issues, such as text-level semantic similarity in code, variations in function hit rates, and the correlation between function names and their respective bodies. Besides, the format and naming conventions of function names may result in false positives in extreme code summaries. In accordance with these observations, further hypotheses are formulated to improve automatic code summarization, including from the perspective of underutilization of function body semantics by neural models and potential issues related to dataset preprocessing.

- To verify our hypothesis, we conducted the ablation experiments based on the selected models. We discovered that phrases with similar semantics have a greater impact on false negatives in generated summaries, while the format of function names has a stronger influence on false positives in the results. Subsequently, we provide directions for improvement in three aspects: dataset preprocessing, external data source and the model's learning process. These directions serve as a valuable reference for future research in the field.

## II. RELATED WORK

### A. Overview of Common Models in the Field of Code Summarization

At present, several representative neural models which can be used to perform the task of code summarization in relevant field, including CODE-NN [10] model based on attention mechanism, Deep-Com [11] model based on code structure analysis, summary generation model based on reinforcement training and so on. Several classic code summarization models are as follows.

- CODE-NN is an end-to-end summary generation system built directly by using the structure of circular neural network, and relevant summary are generated according to the word vectors of source code. The introduction of attention mechanism not only highlights the contribution of key words in the decoding process, but also solves the problem that the summary generated by long code is difficult to understand.

- The code summarization model based on sequence-to-sequence learning algorithm [12] is also popular. The encoder and decoder of this model are built by independent LSTM neural networks, which can extract lexical features of source code and generate summaries. It inputs the key vocabulary sequence of the source code function and outputs the English summary related to the function.

- Deep-Com [11] based on code structure analysis is also a mainstream model in this field. To extract the hidden structural information in the source code, Deep-Com firstly outputs the summary syntax tree as a sequence of nodes in a specific order through a special traversal algorithm [13], and then generates the summary of the target code by using the classic encoder-decoder model. The author thinks that the traversal algorithm used by Deep-Com can express the structural characteristics of the summary syntax tree without loss, and the generated summary can also accurately describe the functional characteristics of the source code.

- The reinforcement learning model for parameter training based on actor-critic mode recently proposed by wan et al gradually becoming popular [14]. Different from the common code summarization model in the field, the author innovatively uses reinforcement learning to update the model parameters, which can further reduce the exposure bias.

In addition, there are also several neural models that can be used directly to perform the task of extreme code summarization, such as Code2Vec, Code2seq, Code-Transformer are shown below:

- Code2Vec [15], which transforms code fragments into vectors with fixed length and continuous distribution, which can be used to predict the semantic information of code fragments. To achieve this goal, Code2Vec is first decomposed into a set of paths in its corresponding AST, and then the neural network is used to learn the representation of each path and how to integrate the representations of all paths. The effectiveness of Code2Vec has been verified by the task of predicting the function name with vector representation of function body.

- Code2seq [16], which uses the syntax structure in programming language to encode the source code. In this model, a part of paths are extracted from AST of code fragments, and the target sequence is generated by Attention after LSTM coding. Code2seq uses the way of encoding the sample of code fragment AST to extract grammatical information better. The effectiveness of Code2seq has been verified in the extreme code summarization task.

- Code-Transformer [17], which jointly learns the sequential and structural information in source code. Compared with other neural models, it only depends on language-independent features, and can directly calculate the source code and features from AST. The performance of the Code-Transformer model is also validated on the task of predicting function name based on function body.

Although the above models have good performance in code summarization generation, due to the lack of learning about structural information or semantic information of source code, sometimes it is inevitable that the generated summaries are difficult to understand or have poor readability.

## B. *Performance Analysis of Code Summarization Model*

The code summarization algorithm based on deep neural network uses the neural machine translation technology to select the corresponding words from the corpus according to the maximum similarity principle with the help of the previous generated words. It transforms the sequence data by using the good transformation ability of the classical encoder-decoder framework, which transforms the source language sequence into the target language sequence. The classic structure has achieved good translation results, despite of the obvious structural and hierarchical characteristics of programming languages, when the neural machine translation method is applied to the generation of code summary, the source code will be treated as an ordinary text. This will inevitably cause the lack of source code structure and make the summarization effect of neural code summarization algorithm worse. Generally speaking, the accuracy of automatic code summarization system based on neural network is not high [18].
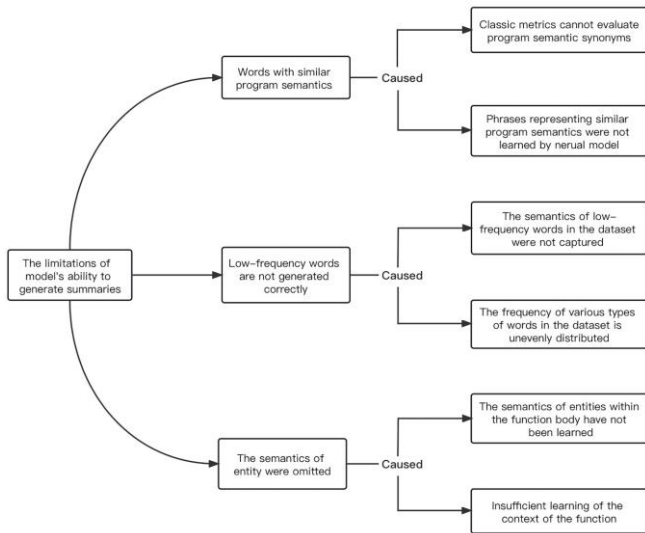


Fig. 1. The limitations of the model's ability to generate summaries.

To sum up, the neural model algorithm used for code summarization has two limitations, as shown in Fig. 1. First, only the sequence information in the code is taken into account by the encoder-decoder structure while the hidden semantics such as the structural information in the code are ignored [19] [20]. Second, the neural code summarization model based on maximum similarity will encounter the problem that low-frequency words or unknown words in the training data cannot be generated correctly during testing [21][22]. In this situation, even if the training data set is large enough and the quality is good enough, low-frequency words cannot be generated correctly; Moreover, when the summary model is applied to a code file in a different domain, there is also the problem of not being able to generate an accurate summary because of words for related domains that are not present in the training set. Above two kinds of findings are the main problems of neural code summarization algorithm.

Although scholars in related fields have identified these hidden dangers, there is currently no targeted solution for these specific problems in code summarization. Therefore, our study attempts to analyze the generated summaries by neural models to observe these phenomena and propose improvement ideas.

## III. RESEARCH METHODOLOGIES

### A. *Extreme Code Summarization Task*

To observe the utilization of program semantics in automatic code summarization, we conducted an experimental study by analyzing the acceptability of the code summaries generated from neural models. To determine whether our experiment can be generalized to different versions of the neural models, we re-implement the neural models from three selected studies as extreme code summarization solutions. The executive process of the neural model for the task of extreme code summarization is shown in Fig. 2. These neural models are trained by different procedures and can be used directly.
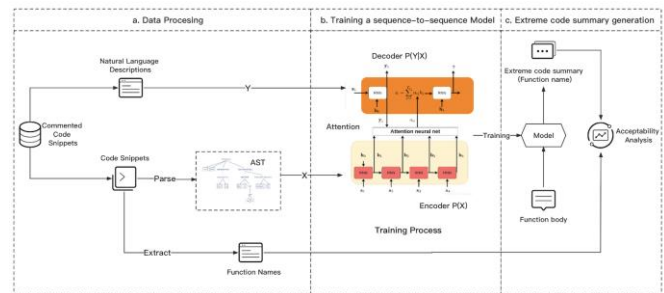


Fig. 2. Overview of models for extreme code summarization.

For the sake of better evaluating the universality of our research, we selected three representative models from different categories. Their different architectures may result in different focuses on learning source code semantics. Among them, code2Vec extracts AST path from the abstract syntax tree (AST) of Code, learns the vector representation of each path through the deep learning model and how to aggregate multiple paths into one vector to represent the entire Code; Code2seq uses LSTMs to encode paths node-by-node (rather than monolithic path embeddings as in code2vec), and an LSTM to decode a target sequence (rather than predicting a single label at a time as in code2vec); Code-Transformer is a Transformer based architecture that learns both source code (context) and an abstract syntax tree (AST) for parsing. In view of their different model architectures result in different ways of learning source code semantics, we infer that there may also be some differences in the generated summaries.

Therefore, Code2vec, Code2seq and Code-Transformer represent a set of diverse but representative models. Using the same dataset to evaluate the task of extreme code summarization on Code2vec, code2seq, and code-transformer highlights the potential risk of false negative and false positive generation when using neural models. Although we can't say for sure, other neural models trained on similar data set may exhibit similar behavior.

### B. *Dataset*

For the task of extreme code summarization, a high-quality dataset plays a crucial role in the quality and acceptability of

the summary generated by neural model. Therefore, we chose the Java dataset proposed by Hu et al., which has been used to evaluate code summarization models such as Code-NN and Deep-Com by using common metrics of bleu, rouge, and meteor, and has achieved relatively complete experimental results.

Java dataset [5], including Java methods extracted from Java projects from 2015 to 2016, collected from GitHub. The first sentence of Javadoc is extracted as a natural language description, which describes the functions of Java methods. The quantity distribution of the dataset is shown in Table I.

TABLE I.        JAVA DATASET STATISTICS

| Dataset | Samples |
|---|---|
| Train | 26142 |
| Test | 8714 |
| Validation | 8714 |

## C. Evaluation Metrics

In order to better evaluate the quality of generated extreme code summaries, we selected three commonly used metrics in the field of code summarization: bleu, rouge, and meter.

*1) BLEU*: BLEU is used to compare the overlapping degree of n-gram in candidate translation and reference translation [23]. N-gram accuracy refers to the ratio of the total number of n-gram matches between the evaluated generated summary and the reference summary to the total number of n-grams in the reference summary. BLEU is often applied to evaluate the similarity between generated summary and reference text.

$$BLEU\_N = BP \cdot (\exp \sum_{n=1}^{N} \omega_n \log p_n) \qquad (1)$$

Here Pn refers to the accuracy rate of n-gram; Wn refers to the weight of n-gram; BP is a penalty factor.

*2) ROUGE*: ROUGE is a quality evaluation method of text summary based on recall, it calculates the similarity between generated summary and reference text [23]. ROUGE-L is often applied to evaluate the quality of code summarization.

$$ROUGE - N = \frac{\sum_{S\in\{Reference\}}\sum_{gram_N \in S} Count_{match}(gram_N)}{\sum_{S\in\{Reference\}}\sum_{gram_N \in S} Count(gram_N)} \qquad (2)$$

The denominator of the formula here is to count the number of n-grams in the reference translation, while the numerator is to count the number of n-grams shared by the reference translation and the machine translation [24].

*3) Meteor*: Meteor is used to calculate the score based on the clear word-word matching degree between the generated summary and the reference text [23], so it is often applied to evaluate the quality of the generated summary according to the score.

$$METEOR = \left(1 - \gamma \cdot \left(\frac{ch}{m}\right)^\beta\right) \cdot \frac{P \cdot R}{\alpha \cdot P + (1-\alpha) \cdot R} \qquad (3)$$

Here, P and R are 1-gram accuracy and recall, $ch$ is the number of blocks, M is the matching number.

*4) Limitations of metrics:* These three types of metrics are all calculated based on the degree of matching at the text level, and cannot be used to evaluate the degree of semantic similarity. All of them have a clear bias towards the order of words, which may lead to some false negatives and misjudgments in the results of extreme code summarization.

## IV. EXPERIMENTS

### A. Research Questions and Experimental Process

In order to explore the acceptability of the code summaries generated from neural models, we re-implement the models of code-transformer, code2vec and code2seq to perform the task of extreme code summarization, and conduct statistics and analysis for the preliminary experimental results. We found that different models have different qualities for summaries generated from the same piece of code, such as the length of generated summaries and the omission of semantic information.

Based on relevant development experience and previous research evidence, we propose the following research questions regarding the preliminary results of the task of extreme code summarization:

RQ1-1: How effectively do existing models employ program semantics for text-level matching?

RQ1-2: Why do many generated function names shrink in length compared to the original function names in the extreme code summaries generated by neural models?

RQ1-3: Whether different types of naming styles of function names affect the accuracy of the model in capturing semantics?

RQ2-1: Whether some synonyms representing the same program semantics can be identified during model learning?

RQ2-2: Whether the model's ability to capture the semantics of verbs greater than that of nouns?

RQ2-3: Will neural models only capture the semantics of words with the same name as function names while ignoring other important semantics?

Afterwards, we will design our experimental plan based on these research questions. The experimental process steps are shown in the following Fig. 3, and the experimental design plan and result analysis are shown in Section IV(B).

### B. Experimental Analysis

We re-implement the models of code-transformer, code2vec and code2seq to perform the task of extreme code summarization, and get the preliminary experimental results. Then we use BLEU metric to divide the hit degree into four levels, we define the BLEU value greater than 0.7 as a high hit level and the BLEU value between 0.3 and 0.7 as a low hit level [25]. We calculated the proportion of the data sets

generated by the three models in each hit level; the preliminary experimental results are shown in Table II:
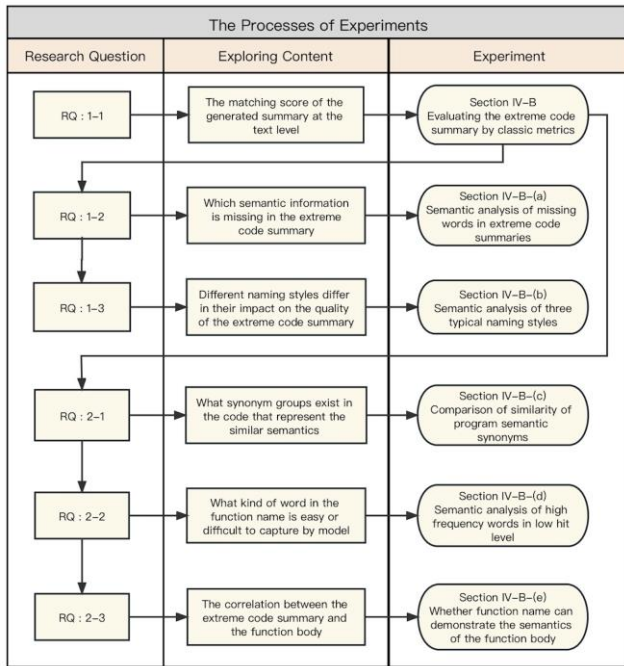


Fig. 3. Experimental process.

TABLE II. Hit Level Category

| Hit level | BLEU | Code2Vec | Code2Seq | Code-Transformer |
|---|---|---|---|---|
| Code-Equal | 1.0 | 17.8% | 18.1% | 19.8% |
| High-Match | 0.7~1.0 | 34.7% | 36.9% | 38.9% |
| Low-Match | 0.3~0.7 | 32.8% | 31.5% | 31.4% |
| Code-Wrong | 0~0.3 | 13.1% | 12.8% | 8.2% |

From the above results in Table II, we found that there are many low matching phenomena between the extreme summaries generated by three models and the original function names. After an intuitive exploration of the generated summaries with the models trained from a Java dataset and based on relevant program development experience, we identify five acceptability aspects to be analyzed in detail: (a) the format of the function name; (b) function name naming style; (c) the semantic similarity in code; (d) the differences in hitting rate of functions; (e) the correlation between function name and function body. We found that the above five aspects of problems are common in the results generated by the three models, so we chose the Code-Transformer model with the best experimental result to analyze its result data from these five aspects in detail. The analytical process of the experiments as follows:

*1) The format of the function name*: We conducted preliminary observations on the generated results of models and found that it is very common that the generated extreme code summary is inconsistent with the length of the original function name after word segmentation. Compared with the

length of the original function name, part of the extreme code summary generated by the model shrinks and part of the extreme code summary extends. Then, we counted the proportion of each phenomenon to analyze whether these phenomena are caused by the model's omission or analytic error of the semantic information of the function body.

TABLE III. The Format of the Function Name

| Preliminary experimental analysis | We compared and analyzed the length of the original function name and extreme code summary. |
|---|---|
| Observation and discovery | The generation of extreme code summaries has more shrinkage phenomenon and less extension phenomenon. |
| Put forward hypothesis | The semantic information within the function body has not been fully extracted and utilized by the neural model. |
| Verification Experiment | Which semantic information in function name were missed during the learning process of neural model. |
| Problem Analysis | The semantic information of function body is not fully utilized by neural model. |

The analysis process is shown in Table III. Firstly, we do word segmentation for the original function names and the extreme code summaries and compare the length of them. Then we divided the results into three categories for statistical analysis, the ratio of them is shown in the Fig. 4. We observed that among the three categories, The model has more shrinkage and less extension for the generation of function names. Therefore, we put forward the hypothesis that the semantics of function is not fully extracted and utilized by neural model, leading to the serious shrinkage phenomenon.
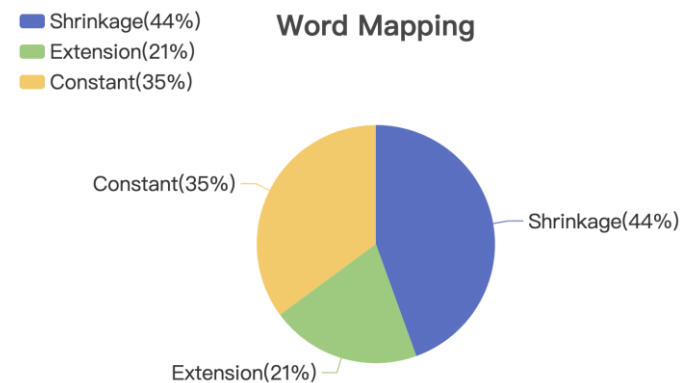


Fig. 4. Word length mapping.

In order to verify the hypothesis, we conducted a verification experiment; we analyze the function name, parameter list and function body in three categories respectively from the following two scenarios.

- Shrinkage Scenario: (including 3166 pieces of data): Function names in this category map from multiple words to fewer words. For example, the noun information in the parameter list of function is omitted: We select three types of the highest frequency verbs (get, set, add) to analyze their representative examples as shown in Table IV:

TABLE IV.        THE HIT RATIO OF SHRINKAGE WORD

| Origin_name | Prediction_name | Percentage |
|---|---|---|
| **getProperties(Properties)** | **get** | **36%** |
| setDisplay(dsiplay) | set | 23% |
| addRenderer(Renderer) | add | 21% |

- Extension Scenario: (including 1069 pieces of data): Function names in this category map from fewer words to multiple words. For example, a preverb is added before the noun in the function name. Then we selected three kinds of data with the highest frequency according to the frequency of occurrence as shown in Table V below:

TABLE V.        THE HIT RATIO OF EXTENSION WORD

| Origin_name | Prediction_name | Percentage |
|---|---|---|
| **id** | **getid** | **19%** |
| Max | getMax | 11% |
| XML | setXML | 8% |

Problem analysis: From the verification experiment results, we can conclude that part of the semantic information of the function body (such as the nouns in the parameter list) has been ignored during the process of model learning, which leads to the highest proportion of shrinkage in the results, resulting in the false positive in generated results.

*2) Naming style of function name*: Based on the preliminary observation of the results generated by the models, several representative words were selected and classified according to the program development experience: (1) Function names starting with "is" to indicate the judgment semantics; (2) Function names containing conjunctions (such as "to", "as", "of"); (3) Function names starting with common verbs. We want to explore how these different naming styles differ in generated extreme code summaries. The analysis process is shown in Table VI.

TABLE VI.        FUNCTION NAMING STYLE

| | |
|---|---|
| Preliminary experimental analysis | We selected several representative categories to classify the function names. |
| Observation and discovery | Function names with different naming styles appear in different hit levels. |
| Put forward hypothesis | Some commonly used conjunction words in function names will cause false positive in generated results. |
| Verification Experiment | Whether the semantics of function names with different naming styles can be fully captured |
| Problem Analysis | Function names with conjunctions and judgment words are not further preprocessed. |

Firstly, we made quantitative statistics on their frequency in four different hit levels, as shown in the Fig. 5. Then we find that in the category of function names representing judgment, the proportion of low hit level is significantly higher than that of high hit level; In the category of function names containing conjunctions, the ratio difference between low and high hit

levels is larger than that of the category representing judgment. In the function name category consisting of verb and noun classes, there is little difference in the proportion of low and high hit level. Therefore, we put forward the hypothesis that these function names with representative naming styles are not preprocessed, so the classic metrics cannot evaluate them correctly and result in false positive results.
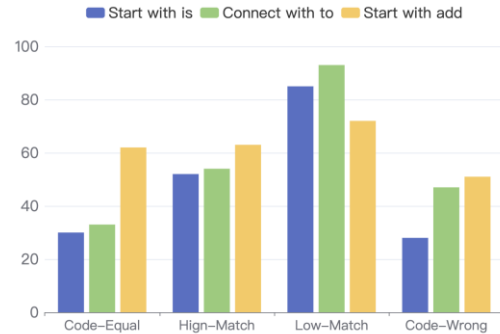


Fig. 5.    Hit frequency in different level.

In the verification experiment, we compare the original function name with the generated function name data set after word segmentation. In the category of low hit level, we check for missing connectors in the generated extreme code summaries. However, the result is not as we expected, the conjunction such as "to" have not been omitted. We also find that the main reason why such words appear in low hit level frequently is that the nouns immediately after conjunctions are often omitted. Therefore, our hypothesis that conjunctions are omitted was overturned.

In the category of representing judgment function names starting with "is", the neural model focuses on capturing the semantic information of embedded function names during the learning process, resulting in a high frequency of occurrence in the category with a lower hit level.

In the category where the function names consisting of verb and noun, we infer that the noun that carries the important semantic information of the function body is often omitted, which leads to the phenomenon of false negative in result. Then we selected a representative high-frequency word in each of three categories and calculated their proportion in the same category is shown in the Table VII below.

TABLE VII.        THE HIT RATIO OF REPRESENTATIVE WORDS

| Origin_name | Prediction_name | Analysis | Percentage |
|---|---|---|---|
| isDoubleFile | isFile | Embedded function | 4% |
| tobyte | tostring | Error in capturing business semantics | 3% |
| **addRenderer** | **add** | **Parameter nouns are omitted** | **7%** |

Problem analysis: From the verification experiment results, we can conclude that due to much important semantic information is not captured during model learning, resulting in the false positive in generated results.

*3) The semantic similarity in code*: We conducted preliminary observations on the results generated by the models and found that some frequent words in function names have specific program semantics; These words with special program semantics have more similar variants in the actual code, that is, there is the semantic similarity in program representation, and these variants can describe the semantics of similar function bodies. Therefore, we put forward the hypothesis that these phrases with similar program semantics cannot be captured by neural model; moreover, the metric cannot evaluate their similarity and result in false negative results.

TABLE VIII.   THE SEMANTIC SIMILARITY IN CODE

| Preliminary experimental analysis | We searched program semantic synonyms by wordnet thesaurus and artificial selection. |
|---|---|
| Observation and discovery | A lot of function names have similar variants in code, which can describe the similar semantics. |
| Put forward hypothesis | The semantic similarity in code cannot be evaluated by classic metrics. |
| Verification Experiment | Evaluation of representative synonyms with the same program semantics. |
| Problem Analysis | Function names with similar program semantics are not captured by neural model. |

The analysis process is shown in Table VIII. Firstly, 213 pairs of synonyms identified from wordnet thesaurus were integrated with 84 pairs of synonyms selected manually for k-means cluster analysis, then four groups of synonyms with the highest frequency were selected, as shown in the Fig. 6.
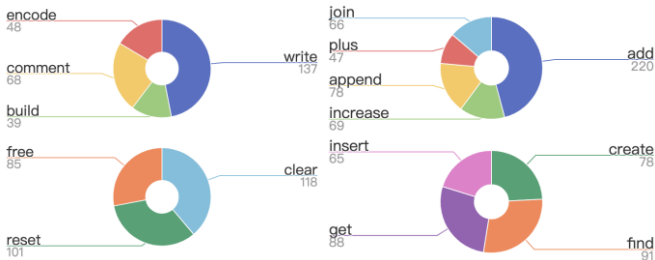


Fig. 6.   The four highest frequency synonym groups.

To verify our hypothesis, we use the bleu metric to calculate the similarity of each group of words after stemming, and the results of similarity calculation are all 0%, as shown in the Table IX, but the synonyms in each group can all represent the semantic of the function body. So it can be seen that the model will produce false negative results because these verbs with similar program semantics cannot be captured by neural model and evaluated by classic metrics.

TABLE IX.   SEMANTIC SIMILARITY OF SYNONYMS

| Origin_name | Prediction_name | Similarity |
|---|---|---|
| add | increase, append, plus | 0% |
| create | find, get, insert | 0% |
| write | build, comment, encode | 0% |
| clear | free, reset | 0% |

Problem analysis: From the verification experiment results, we can conclude that since function names with similar program semantics are not captured by neural models, resulting in the false negative in generated results.

*4) The differences in hitting rate of functions*: We have preliminarily observed the generated results of models: The four types of words ("add", "remove", "write", "read") that represent addition, deletion, modification and selection in database operation for a high proportion in the generated results, and each type of words has a certain frequency in different hit levels. We want to make statistics on the occurrence frequency of these four representative words in different hit levels to explore whether the semantic of function body is not fully utilized, leading to the occurrence of these representative words in low hit levels.

TABLE X.   THE DIFFERENCES IN HITTING RATE OF FUNCTIONS

| Preliminary experimental analysis | We count the hitting ratio of four high-frequency verbs in different hitting levels. |
|---|---|
| Observation and discovery | High frequency words also appear frequently in low hit levels. |
| Put forward hypothesis | Common prefix verbs in function names can cause false positives in the generated extreme summary. |
| Verification Experiment | Whether function names that only contain verbs can represent the semantics of the function body. |
| Problem Analysis | Many nouns that represent business semantics have not been captured by neural model. |

The analysis process is shown in Table X. We sampled four kinds of verbs with the highest frequency from the data set including the "verb + noun" combination whose first word is this verb, the four kinds of verbs are "add", "remove", "write" and "read" respectively.
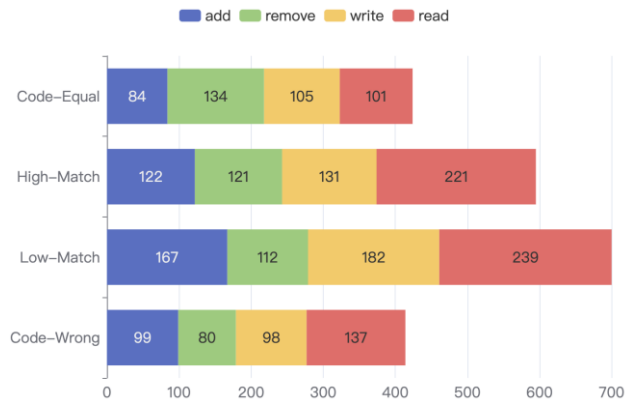


Fig. 7.   Four kinds of words hit frequency in different level.

Then, we count the numbers of these four words in above four hit levels proposed in Table II, the statistic results are shown in the Fig. 7. By preliminary observation, we find that four types of words appear frequently both in high hit and low hit levels, so we put forward the hypothesis that the semantics in function body are not fully extracted and utilized by the neural model, which leads to false negative results.

To verify our hypothesis, we made a statistical analysis on the function body of four kinds of words extracted from the original data set. We observed that there are embedded function names with the same name as the extreme code summary generated by neural model in these function bodies, which may cause the model to ignore the semantic information of other nouns within the function body, and leads to the false negative results of the model. Then we calculate the proportion of highest frequency words in four types of categories in the low hit level as shown in Table XI:

TABLE XI. THE HIGHEST HIT RATIO OF FOUR TYPES OF WORD

| Origin_name | Prediction_name | Percentage |
|---|---|---|
| add | append | 31% |
| **remove** | **delete** | **44%** |
| write | encode | 26% |
| read | find | 30% |

Problem analysis: From the verification experiment results, we can conclude that due to the fact that many nouns that represent business semantics in the function body, except for verbs, has not been captured by the model during learning process, resulting in false negative in generated results.

*5) The correlation between function name and function body*: By comparing the generated extreme code summary with the function body of the original data set, we find that many generated extreme code summaries are inconsistent with the original function names, but they are consistent with the embedded function names in the original function body. We propose the hypothesis that this phenomenon may be caused by the model concentration learning the semantics of the embedded function body while ignoring other important semantics.

TABLE XII. THE CORRELATION BETWEEN FUNCTION NAME AND FUNCTION BODY

| Preliminary experimental analysis | We compare the generated function name with the function body of the original dataset. |
|---|---|
| Observation and discovery | Many generated function names are consistent with the embedded function names in the function body. |
| Put forward hypothesis | The semantic information of the function body was not fully captured by the model. |
| Verification Experiment | Whether embedded function names can represent the semantics of their function body. |
| Problem Analysis | Other important semantic information within the function body was not captured by neural model. |

Embedding function name: First, we define the embedded function name: that is, the function name that appears in a one-line statement in the function body. For example, "write" is the embedding function name in Fig. 8 below.

```java
public void write (String key, byte[] newValue) {
    Map<String, byte[]> entry = new HashMap<>();
    entry.put(key, newValue);
    write(entry);
}
```

Fig. 8.    The embedded function name "write".

The analysis process as shown in Table XII. According to the development experience, we classify these embedded function names into four categories: (1) including common verb, (2) including conjunctions, (3) mathematical functions, (4) representing judgement category; We count the function names with the highest frequency in these four categories by frequency, the result as shown in the Fig. 9.
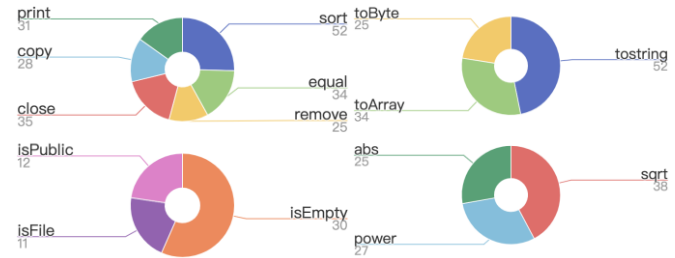


Fig. 9.    The high frequency words in four groups of phrases.

To verify the hypothesis, we counted and analyzed the mapping number between the above four class function names and the function names embedded in the function body.

There are 1139 pieces of data embedded with the same function name as the original. We selected the three most frequent words and calculated their proportion in their category as shown in the Table XIII below.

TABLE XIII. THE HIGHEST HIT RATIO OF CONSISTENT WORD

| Origin_name | Prediction_name & Embedded function name | Percentage |
|---|---|---|
| **Sort** | **sort** | **11%** |
| Tostring | tostring | 9% |
| IsEmpty | isEmpty | 9% |
| Sqrt | sqrt | 5% |

There are a total of 478 extreme code summaries that are the same as the embedded function names in the function body, but different from the original function names. It can be seen that the model concentrates on learning the local program semantics of some embedded functions while ignoring other semantics in function body, which leads to the false negative result of the model. We selected three kinds of verbs with the highest frequency for statistical analysis as shown in the Table XIV below.

TABLE XIV.   THE HIGHEST HIT RATIO OF INCONSISTENT WORD

| Origin_name | Prediction_name & Embedded function name | Percentage |
|---|---|---|
| copy | write | 14% |
| delete | remove | 13% |
| reset | clear | 8% |

Problem analysis: From the verification experiment results, we can conclude that due to the fact that many semantic information other than embedded function name in the function body was not captured by neural model, resulting in false negative in generated results.

### C. Ablation Study

Based on the statistical study of these five aspects, to further explore the impact of various aspects on the model's ability to capture semantics hidden in source code, we conducted the ablation experiment, in which we respectively improve the preprocessor statement of data sets in terms of function name format, function naming style, semantic level similarity, the differences in hitting rate of functions and the correlation between function name and function body, then we evaluate the ablation experimental results by using Bleu, Rouge and Meteor metrics, as shown in Table XV.

*1) False negative aspect*: In terms of the three aspects that produced false negative results, we performed the following ablation experiments.

*a) The differences in Hitting Rate of Functions*: We filter four types of high-frequency verbs in low hit level category.

*b) The Correlation between Function Name and Function Body*: We filter the function name data set which omits nouns in the parameter list from the data set whose embedded function name is inconsistent with the original function name.

*2) False positive aspect*: In terms of the two aspects that produced false negative results, we performed the following ablation experiments:

*a) The Format of the Function Name*: We filter the function name data set with omitted parameters in the function name data set with shrinkage scenario.

*b) The Naming Style of Function Name*: We filter out "is" in the function name data set of representing judgment class; We filter out the pre-verbs in the data set of the function name consisting of verb and noun; We don't deal with the conjunctions.

*3) Ablation result*: Ablation experiment results (Table XV) show that semantic similarity in program has a stronger influence on false negative in results, the format of function name has a stronger influence on false positive in results.

### D. Insights Gained From Experiments

Based on the analysis of experimental results and further validation of ablation experiments on the above research questions, we can make some improvements to the model for executing the task of extreme code summarization in terms of preprocessing filtering enhancement, external data source enhancement, and attention mechanism enhancement. The specific optimization steps are outlined in red dashed lines in Fig 10.

*1) Preprocessing filtering enhancement*: For the cases of different types of naming styles of function names in section B-b and function names with high correlation with function bodies in section B-e, we will seek optimization from the perspective of data preprocessing. We plan to filter out common prefixes of data words with specific naming styles and embedding function names during the preprocessing process to reduce the occurrence of false positives in the generated results.

*2) External data source enhancement*: For the situation that the synonym group representing the same program semantics in section B-c cannot be recognized by the program, we plan to import the constantly improving program semantic synonym library as an external data source and integrate it with summary information during the model training process, so that the neural model can gain data enhancement in the process of learning the text of summary to avoid false negatives in the generated results.

TABLE XV.   ABLATION EXPERIMENTAL RESULT

| Aspect | | Code2Vec | | | Code2Seq | | | Code-Transformer | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | BLEU | ROUGE-L | METEOR | BLEU | ROUGE-L | METEOR | BLEU | ROUGE-L | METEOR |
| False Negative | **Semantic Similarity** | **48.85** | **63.86** | **31.79** | **51.81** | **63.84** | **32.77** | **52.88** | **64.89** | **29.83** |
| | Classification Hit Rate | 39.79 | 54.81 | 25.74 | 40.76 | 53.82 | 24.75 | 42.84 | 53.87 | 21.78 |
| | Func_Body_Correlation | 37.98 | 52.80 | 22.70 | 39.74 | 51.81 | 23.71 | 40.82 | 50.83 | 20.76 |
| False Positive | **Naming Format** | **47.54** | **58.51** | **30.49** | **49.52** | **60.50** | **29.46** | **50.59** | **59.61** | **32.53** |
| | Naming Style | 37.58 | 52.55 | 21.54 | 38.54 | 49.54 | 18.52 | 41.62 | 51.63 | 23.56 |
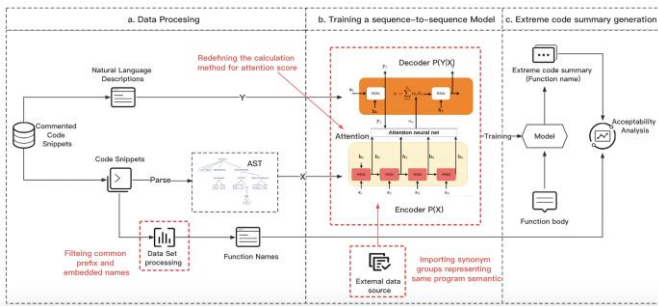
Fig. 10. The Diagram of model architecture for extreme code summarization.

*3) Enhancement of attention mechanism*: For the cases where the important program semantics in section B-a and the noun semantics in section B-d are omitted during the model learning process, we will seek optimization from the perspective of attention mechanism. In the attention mechanism, each piece of information is assigned a different attention score. If the attention score of important semantic information is low, it may cause the output sequence information to lose this part of semantics. Therefore, we can try to innovate in the calculation methods of attention score, such as dot product, multiplication, addition, or other more complex calculation formulas, then assign new attention score to each information, so as to improve the attention score of important semantic information and avoid false positives in the results as much as possible.

## V. Threat to Validity

*1) Model re-implementation*: In the process of reimplementing the three models, the word length of some data sets exceeds the limit. For example, the length of words in the function body of code-transformer cannot exceed 1200, and the length of code2vec and code2seq exceeding 900 will also cause model parsing failure. In order to avoid this situation, we need to filter out relevant nonconforming data in the process of data set preprocessing.

*2) Selected dataset:* Java dataset has a total of 8714 pieces of data. Although the sample data is of high quality and representative, and the domain knowledge is perfect, the overall scale is small. If we want to retrain the data set of the model in the future, we should inject a larger data set.

*3) Model comparison*: We choose the three represents extreme code summary generation model. In our experiment, we use the same data set, run all models in the same hardware environment, and adopt the same data preprocessing process to reduce this threat.

## VI. Conclusion

Many studies show that the quality of code summary generation algorithms based on deep learning is not ideal because it does not take full advantage of relevant program semantic information. In this paper, in order to observe the utilization of program semantics in automatic code summarization, we conducted an experimental study by analyzing the acceptability of the code summaries generated

from neural models. To focus on the observation of the semantics, we re-implement the neural models from three selected studies as extreme code summarization solutions. Fig. 10 shows the diagram of model architecture for extreme code summarization. After an intuitive observation and exploration of the generated summaries with the models trained from a Java dataset, we identify five acceptability aspects: (1) function name format; (2) function naming style; (3) semantic level similarity; (4) the differences in hitting rate of representative words; (5) the correlation between extreme code summaries with function body. Experimental analysis shows that false negative is common in the results if only evaluated with classic metrics, and aspects (3)(4)(5) bring the major influence. We also observed that false positives related to aspects (1)(2) also commonly appeared in the result, which suggests that the current models also fail to filter the noise from the raw source code to a reasonable extent.

We put forward hypotheses for these above five aspects, for example, the semantics of the function body may not have been fully learned by neural model. Then we designed and completed relevant verification experiments to prove whether our hypotheses are correct. The verification experiment confirmed that aspects (2)(5) is caused by insufficient preprocessing of the data set, aspects (1)(3)(4) are caused by the semantics of function body have not been fully extracted and utilized by neural model.

To further explore the influence of the above five aspects on the quality of extreme code summaries, we conducted ablation experiments which indicated that aspect (3) had a stronger influence on false negative in extreme code summarization results than the other aspects (4)(5), The aspect (1) has a stronger influence on false positive in extreme code summarization results than aspect (2). The results of ablation experiment illustrate prove the significance and potential of utilizing the program semantics explicitly in code summarization.

Therefore, based on the experimental results and findings, in the future study, we plan to improve the model in performing code summarization tasks from three aspects of preprocessing filtering enhancement, external data source enhancement and attention mechanism enhancement, which have been mentioned in section IV-D. Let's wish all these findings promote the progress in the field of code summarization.

## References

[1] Allamanis M, Barr ET, Devanbu P, et al. Code Generation as a Dual Task of Code Summarization [J]. ACM Computing Surveys (CSUR), 2020, 51(4): 1-37.

[2] Miltiadis Allamanis, Earl T Barr, Premkumar Devanbu, and Charles Sutton. 2017. A Survey of Machine Learning for Big Code and Naturalness. arXiv preprint arXiv:1709.06182 (2017).

[3] Raychev V, Vechev M, Krause A. Predicting program properties from" big code"[J]. ACM SIGPLAN Notices, 2015, 50(1): 111-124.

[4] Parisotto E, Mohamed A, Singh R, et al. Neurol-symbolic program synthesis[J]. arXiv preprint arXiv:1611.01855 (2016).

[5] Liu S, Chen Y, Xie X. A Convolutional Attention Network for Extreme Summarization of Source Code [J]. arXiv preprint arXiv:1802.03691 (2017).

[6] Wang K, Singh R, Su Z. Reassessing Automatic Evaluation Metrics for Code Summarization Tasks [J]. arXiv preprint arXiv:1711.07163(2020).

[7] Paras Jain, Ajay Jain, Tianjun Zhang, Pieter Abbeel, Joseph E. Gonzalez, and Ion Stoica. 2020. Contrastive Code Representation Learning. *CoRR* abs/2007.04973 (2020).

[8] Chin-Yew Lin. 2004. ROUGE: A Package for Automatic Evaluation of Summaries. In *Text Summarization Branches Out*. Association for Computational Linguistics, Barcelona, Spain, 74–81.

[9] Shangqing Liu, Yu Chen, Xiaofei Xie, Jing Kai Siow, and Yang Liu. 2021. Retrieval-Augmented Generation for Code Summarization via Hybrid GNN. In 9th International Conference on Learning Representations, ICLR 2021, Virtual Event, Austria, May 3-7, 2021.

[10] Monperrus M. Summarizing Source Code using a Neural Attention Model [J]. ACM Computing Surveys (CSUR), 2018, 51(1): 1-24.

[11] Hellendoorn V J, Sutton C, Singh R, et al. Deep code comment generation with hybrid lexical and syntactical information [C]//International conference on learning representations (2018).

[12] Vasic M, Kanade A, Maniatis P, et al. Sequence to Sequence Learning with Neural Networks [J]. arXiv preprint arXiv:1904.01720 (2016).

[13] Guo D, Ren S, Lu S, et al. Graphcodebert: Pre-training code representations with data flow[J]. arXiv preprint arXiv:2009.08366 (2021).

[14] Chen X, Liu C, Song D, et al. Multi-modal attention network learning for semantic source code retrieval[J]. arXiv preprint arXiv:1909.13516 (2019).

[15] Alon, Uri, Meital Zilberstein, Omer Levy, and Eran Yahav. "code2vec: Learning distributed representations of code." Proceedings of the ACM on Programming Languages 3, no. POPL (2019): 1-29.

[16] Uri Alon, Shaked Brody, Omer Levy, Eran Yahav: code2seq: Generating Sequences from Structured Representations of Code. ICLR,2019.

[17] D. Zügner, T. Kirschstein, M. Catasta, J. Leskovec, and S. Günnemann, "Language-agnostic representation learning of source code from structure and context". ICLR, 2021.

[18] Kishore Papineni, Salim Roukos, Todd Ward,et al. BLEU: a Method for Automatic Evaluation of Machine Translation[J]. ACL, Philadelphia, July 2002, pp. 311.

[19] Lei Jimmy Ba, Jamie Ryan Kiros, and Geoffrey E. Hinton. 2016. Layer Normalization. *CoRR* abs/1607.06450 (2016).

[20] Zi Gong, Cuiyun Gao, Yasheng Wang, Wenchao Gu, Yun Peng, and Zenglin Xu. 2022. Source Code Summarization with Structural Relative Position Guided Transformer. *CoRR* abs/2202.06521 (2022).

[21] Xing Hu, Xin Xia, David Lo, Zhiyuan Wan, Qiuyuan Chen, and Tom Zimmermann. 2022. Practitioners' Expectations on Automated Code Comment Generation. In ICSE '22: Proceedings of the 44th ACM/IEEE International Conference on Software Engineering.

[22] Zhongxin Liu, Xin Xia, Christoph Treude, David Lo, and Shanping Li. 2019. Automatic Generation of Pull Request Descriptions. In *34th IEEE/ACM* International Conference on Automated Software Engineering, ASE 2019, San Diego, CA, USA, November 11-15, 2019. IEEE, 176–188.

[23] Paul W. McBurney and Collin McMillan. 2016. Automatic Source Code Summarization of Context for Java Methods. *IEEE Trans. Software Eng.* 42, 2(2016), 103–119.

[24] Wenhan Wang, Ge Li, Bo Ma, Xin Xia, and Zhi Jin. 2020. Detecting Code Clones with Graph Neural Network and Flow-Augmented Abstract Syntax Tree. In *SANER*. IEEE, 261–271.

[25] Lun Yiu Nie, Cuiyun Gao, Zhicong Zhong, Wai Lam, Yang Liu, and Zenglin Xu. 2020. Contextualized Code Representation Learning for Commit Message Generation. *CoRR* abs/2007.06934 (2020).

# Using Topic in Summarization for Vietnamese Paragraph

Dat Tien Dieu, Dien Dinh

Faculty of Information Technology, University of Science, Ho Chi Minh City, Vietnam

*Abstract*—**This article delves into the realm of refining the precision of automated text summarization tasks by harnessing the underlying themes within the documents. Our training data draws upon the VNDS dataset (A_Vietnamese_Dataset_ for_Summarization), encompassing a total of 150,704 samples aggregated from diverse online news sources like vnexpress.net, tuoitre.vn, and more. These articles have been meticulously processed to ensure they align with our training objectives and criteria. This paper presents an approach to text summarization that is theme-oriented, utilizing Latent Dirichlet Allocation to delineate the document's subject matter. The data subsequently have been fed into the BERT model, which constitutes one of the subtasks within the broader domain of abstractive summarization—summarizing content based on pivotal concepts. The results attained, although modest, underscore the challenges we've confronted. Consequently, our model necessitates further development and refinement to unlock its full potential.**

*Keywords*—*Automatic text summarization; a theme-based approach; BERTmodel; latent dirichlet allocation*

## I. Introduction

Text summarization is a method that allows readers to quickly grasp the essential and core contents of a document, reducing reading time while retaining important and necessary information. Text summarization is not only applied in news articles and publications but also in search results, product descriptions, technical documents, and even summarizing related articles within a given topic. One of the earliest studies in the field of automatic text summarization was conducted by Erkan and his colleagues in 2007. Since then, automatic text summarization has become a formal task and has been approached by various research groups and integrated into their language models for evaluation purposes.

In terms of the purpose of text summarization, it can be divided into theme-based summarization and generic summarization. Currently, there are two main approaches to automatic text summarization: extractive summarization, abstractive summarization, and a combination of these two methods known as hybrid summarization.

In this research, the paper focuses on two primary directions related to generating text summaries. The first direction concentrates on extracting information from the original text to create a summary. Methods in this direction emphasize selecting sentences with high coverage in the original text for inclusion in the summary. This can be achieved through graph-based methods [1] or even using neural networks to identify important sentences [2]. The second direction involves creating a summary by abstracting

meaning from the original text. In this approach, machine learning models are used to generate new sentences based on the content of the original text, resulting in a summary with a completely different grammatical structure from the original text. Additionally, there is a hybrid approach that combines extraction and abstraction, creating a summary by extracting information and summarizing a portion of the original text.

All three research directions produce automatic summaries, which are evaluated by comparing them to reference summaries created by humans, using metrics such as BLEU [3] and ROUGE [4].

Our work is based on a dataset of Vietnamese text, which is compiled by aggregating news articles from the VnExpress electronic information portal. After collecting the articles, they are preprocessed to create an experimental dataset. Each document in this dataset consists of two main components: a pre-existing summary called a reference summary and the main content of the article. Then the dataset was divided into three separate parts model training, training parameter tuning, and finally, model evaluation.

## II. Related Works

### A. Model ViHeartBERT (2022)

The ViHeartBERT model (2022) [5] constructs a model with applications in the medical field, designed to help both patients and doctors understand scientific literature by providing clear explanations for medical abbreviations and summarizing frequently asked questions. The dataset used for training is a specialized medical dataset called acrDrAid. This model has a BERTbase-like architecture but is trained on its own dedicated dataset.

### B. Model ViT5 (2022)

The ViT5 model (2022) [6] is an encoder-decoder model based on the Transformer architecture that has been pre-trained for the Vietnamese language. Following the self-supervised T5-style pre-training approach, ViT5 was trained on a large, high-quality, and diverse dataset of Vietnamese text. They assessed the performance of ViT5 on two downstream text generation tasks: Abstractive Summarization and Named Entity Recognition (NER).

ViT5's performance against several other Transformer-based encoder-decoder models. Our experiments demonstrated that ViT5 significantly outperforms existing models and achieves the best results in Vietnamese text summarization. In the Named Entity Recognition task, ViT5 competes strongly

with the previous best results obtained from pre-trained Transformer-based models.

### C. Model BARTPho (2022)

The BARTpho model (2022) [7] is one of the leading and largest single-language sequence-to-sequence models pre-trained for Vietnamese. Our BARTpho model utilizes a "large" architecture and follows the pre-training strategy of the BART long document denoising model, making it particularly suitable for natural language generation tasks.

Tests conducted on a specific task related to Vietnamese text summarization demonstrate that BARTpho, both in terms of automatic evaluation and human assessment, outperforms the strong base model mBART and enhances the current state of the art. BARTpho has been released to support future research and applications in natural language generation tasks for the Vietnamese language.

Based on the promising results of language models, they have decided to train a language model based on a sequential model structure with attention mechanisms and the incorporation of document themes.

### III. PROPOSAL

Following the research above, there is a need for a model that can be used to summarize a paragraph with the topic because using the topic helps to redirect the bag of words to the topic that it should be about, it helps to improve the accuracy of generation words and also the relation between generated text and original one. The attention mechanisms are really powerful but also the topic awareness, the bag of words have been narrowed down, it is easier to control the output to get better-generated text over time.

### A. The Structure of a Sequential Model with Attention Mechanisms

The structure of the Sequence-to-sequence (Seq2Seq) model with an attention mechanism is depicted in Fig. 1 and serves as the foundation for developing the Pointer-generator Networks model. The model consists of:

**Encoder:** This is a bidirectional LSTM network with a single layer. It encodes the input sequence.

**Decoder:** This is a unidirectional LSTM network with a single layer. It decodes the encoded information from the encoder to generate the output sequence.

The document $w_i$ is sequentially fed into the encoder to generate the encoded sequence of hidden states $h_i$.. At each time step t, the decoder receives the embedding of the previous word (during training, it's the word from the reference document, and during testing, it's the word selected at time step t - 1 by the decoder) and obtains the decoding state $s_t$.

The attention distribution is computed according to Eq. (1) and Eq. (2):

$$e_i^t = v^T \tanh(W_h h_i + W_s s_t + b_{attn}) \quad (1)$$

$$a^t = softmax(e^t) \quad (2)$$

where, $v, W_h, W_s$ and $b_{attn}$ are trainable parameters. The attention distribution can be seen as a probability distribution over the vocabulary, informing the decoder about where to look to generate the next word. Subsequently, the attention distribution is used to compute the weighted sum of the hidden states from the encoder, referred to as the context vector $h_t^*$ in Eq. (3):

$$h_t^* = \sum_i a_i^t h_i \quad (3)$$

The context vector, representing a fixed-size vocabulary, is read at the current time step, and it is combined with the decoder state $s_t$ to generate the word probability $P_{vocab}$ as described in Eq. (4):

$$P_{vocab} = softmax(V'(V[s_t, h_t^*] + b) + b') \ (4)$$

where, $V$, $V'$, $b'$ and $b$ are trainable parameters, and $P_{vocab}$ is the probability distribution over all words in the vocabulary, providing us with the distribution of the word to be predicted as given in Eq. (5):

$$P(w) = P_{vocab}(w) \quad (5)$$

During the training process, the loss at time step $t$ is determined by the negative log-likelihood of the word group $w_t^*$ at that step, as defined in Eq. (6):

$$loss_t = -\log P(w_t^*) \quad (6)$$

Subsequently, the loss value for the entire input sequence is determined as per Eq. (7):

$$loss = \frac{1}{T}\sum_{t=0}^{T} loss_t \quad (7)$$
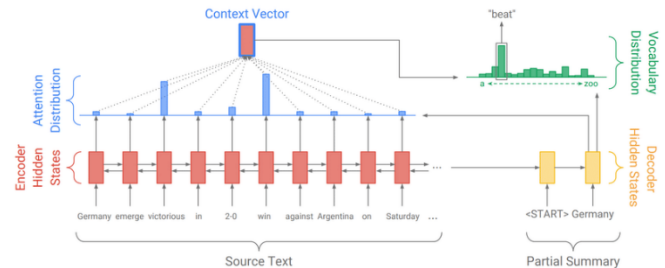


Fig. 1. Structure of sequence-to-sequence attentional model.

Fig. 1 is the structure of the model that was used to feed the data to the model and get the context vector with vocabulary distribution.

### B. The Generative Network Utilizes the Topic Modeling Method with Latent Dirichlet Allocation (LDA)

A model was built to demonstrate the capability of expressing the topic distribution of a text segment as well as an array representing the distribution of words related to those topics from raw data. To achieve this, using Latent Dirichlet Allocation (LDA) is an important part. This information is combined to enhance the accuracy of text summarization. There are several models which have been used to enhance the accuracy of the Natural Language Processing model, which can be referred to as "Latent Dirichlet Allocation (LDA) and Topic modeling: models, applications, a survey" of Hamed Jelodar, Yongli Wang, Chi Yuan, Xia Feng, Xiahui Jiang, Yanchao Li, Liang Zhao [8]. To learn more about how

to apply the LDA for the abstraction summarization, this paper is inspired by "LDA based topic modeling of journal abstracts" by P. Anupriya; S. Karpagavalli [13] about how to use LDA effectively in the summarization in order to get better summarization without using the same words which are in the original paragraph.

To better understand LDA, let's consider an example. having 1000 documents, each consisting of 500 words. This means it would need 1000x500 connections to understand how each word depends on each document and vice versa. Instead of having so many connections, and grouping these documents into topics, let's assume there are three topics. So, there will be 1000x3 = 3000 connections to determine which topics each document belongs to, and another 500x3 = 1500 connection to determine the word distributions that influence these 3 topics.

Fig. 2 and Fig. 3 demonstrate the differences between using an additional topic layer and not using any additional topic layer.
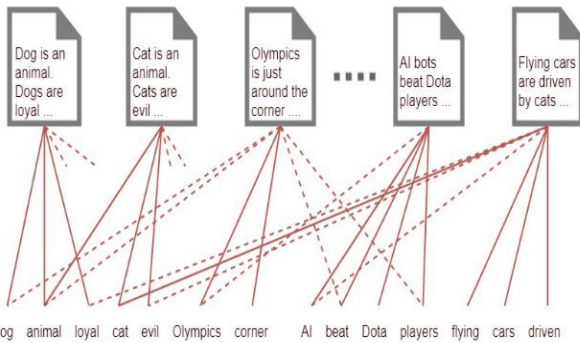


Fig. 2. Connections are necessary to determine the influence of words on documents.
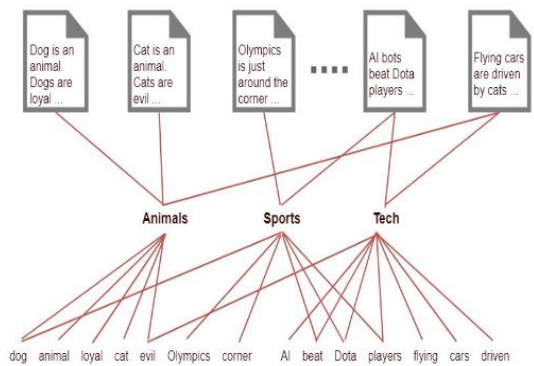


Fig. 3. Connections are necessary to determine the impact of words on the documents through topics.

Once the possible topics are identified within the documents, using CountVectorizer to train the LDA model and obtain the results as follows Fig. 4 is the next step. The distribution of words to the corresponding topic can see how the words are being distributed or which word contributes to which topic.



Fig. 4. Distribution of words to the corresponding topic.

### C. Combining the Generative Network using the LDA Topic Modeling Method with the BERT Model

The Bayesian approach, which is based on the distribution of topics within the input text, can be highly effective for documents that have hidden topics.

$$
\begin{aligned}
decoding\ probability =\ & alpha * sum\_topic[\ p(word\,|\,topic) \\
& * p(topic\,|\,paragraph)] + (1 \\
& - alpha) \\
& * p\_transformer(word\,|\,context)
\end{aligned}
$$

The combination approach of the LDA topic modeling method with the BERT model will be illustrated in the following figure:
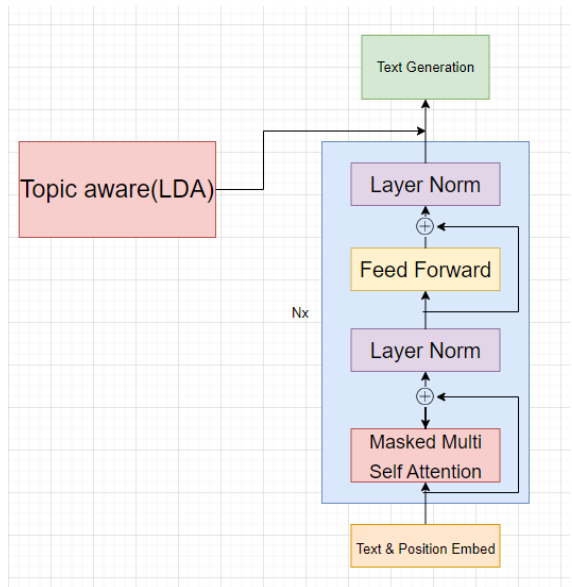


Fig. 5. The combination of BERT and LDA.

Fig. 5 demonstrates where the Topic Aware (LDA) has been added to the original BERT model and the reason for this is because this model has been designed to focus on the last layer before the model generates the words.

## IV. DISCUSSION

The topic-aware approach is also potent, with several papers employing the topic as a primary feature in generating text, following the principles of "Latent Dirichlet Allocation (LDA) and Topic modeling: models, applications, a survey."[8]. This technique proves particularly effective in specific domains with extensive terminology, declarations, definitions, and so forth, such as Social Networks, Software Engineering, Crime Science, Geography, Political Science, and Medical Science. In such areas, where term ambiguity is prevalent, a model that can discern the appropriate words for generation is imperative. Conventionally, LDA has been used not only for topic detection but also to uncover hidden topics within paragraphs. When dealing with a multitude of words, identifying underlying themes can be challenging for humans, but LDA offers a viable solution. "Prediction of research trends using LDA based topic modeling" is also an inspired paper that shows there is a promising trend for using LDA-based topic modeling in the Natural Language Processing industry. The research in [10], an example of using LDA for topic modeling for new articles [12].

Additionally, the BERT model has demonstrated its position as a state-of-the-art (SOTA) innovation in the Natural Language Processing industry. The introduction of the attention mechanism has revolutionized the landscape of methods, paving the way for a more accurate and efficient approach to extracting meaning from text using computers. It stands as the initial and rational choice for fine-tuning in various applications, including our case. Therefore, our ultimate goal is to effectively combine these two methods.

There is a limit characteristic of the BERT model is about the length of input, it is just 256. Because of that, the BERT multilingual model has been used to replace the original BERT model. According to "How Multilingual is Multilingual BERT" by Telmo Pires, Eva Schlinger, and Dan Garrette [9]. Additionally, following the "Pre-training of Deep Bidirectional Transformers for Language Understanding" [11], it is obvious using pre-trained models which have the transformer architecture will be more efficient than other architectures.

## V. EXPERIMENTS

### A. Datasets

This study was experimentally evaluated on a dataset comprising 830,643 articles collected from the Vnexpress website. Each article includes a title, author's summary, and the body of the article. Of this dataset, 80% was used for training, and 10% was used for experimental evaluation. On average, each article contains about 20 sentences, with each sentence consisting of approximately 25 words or fewer.

Table I provides a detailed description of the preprocessed dataset. The data was divided into three sets: Training (Train), Validation (Validation), and Test (Test) in a respective ratio of 70:15:15. The average number of sentences in the summary section across the sets is 1.22 sentences, with approximately 28 words per summary sentence. Meanwhile, the average number of sentences in the text to be summarized is around 17 sentences, with approximately 418 words.

TABLE I. THE DATASET INFORMATION

| | Training Set | Validation Set | Test Set |
|---|---|---|---|
| Numbers of sample | 105,418 | 22,642 | 22,644 |
| #avg number of sentences in abstract | 1.22 | 1.22 | 1.22 |
| #avg number of words in abstract | 28.48 | 28.54 | 28.59 |
| #avg number of sentences in body | 17.72 | 17.81 | 17.72 |
| #avg number of word in body | 418.37 | 419.66 | 418.74 |

### B. Settings

The experiments have been done with the generative network model using a pointer on a computer equipped with a GPU, 12.79 GB of RAM, and a 16GB GPU, running Tensorflow three library. The training parameters were set as follows:

- Number of hidden layers: 4
- Learning rate: 0.001
- Embedding word length: 128
- Beam size: 4
- Number of heads: 8
- Input sentence length: 512
- Output sentence length: 200

### C. Results

Beginning the experimental phase with the LDA training model (a model that determines document topics based on the LDA algorithm). Since the number of topics is not predetermined, attempting to determine the number of topics through several methods is a crucial aspect.

First, the K-means clustering method has been used to determine the number of topics and assess how dividing topics influences the model's generative capability. After performing this, the result is obtained in the following chart:
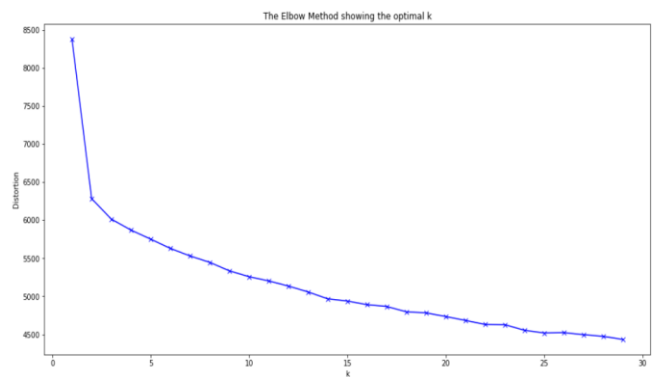


Fig. 6. The distribution of the number of topics when inputting.

Fig. 6 demonstrates the best number of topics that should be divided paragraphs into. Below Fig. 7 shows the distribution of topics in paragraphs, it can be seen obviously the paragraphs have the same topics tend to gather together.
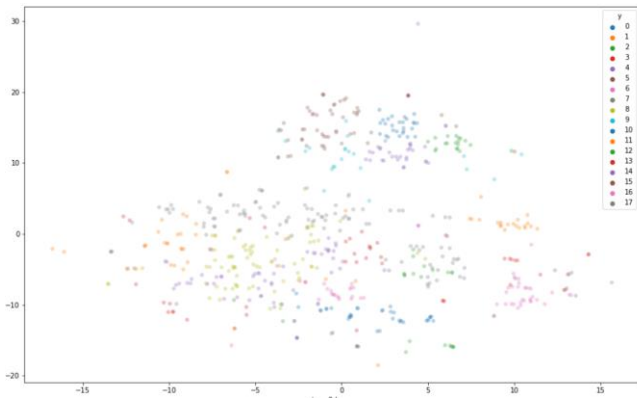
Fig. 7.   Distribution and clustering of topics in paragraph.

To confirm the meaningfulness and accuracy of this representation, T-SNE (t-Distributed Stochastic Neighbor Embedding) examined the distribution and clustering of the data. Fig. 8 demonstrates distribution topics over each paragraph, it can be referred to the contribution of those topics to the big topics in each paragraph.



Fig. 8.   Distribution of topics to each paragraph in the dataset.

With the results above, it shows that the distribution of topics across documents is uneven. This is because different words in different texts have varying meanings.

After completing the LDA experiments, the next experiments are combining LDA with the BERT model. Initially, the BERT model was trained from scratch, meaning there is no pre-trained model used, to assess its effectiveness and training capabilities without a suitable pre-trained model. However, the results were not very good, achieving ROUGE 1, ROUGE 2, and ROUGE L scores of 5.4%, 4.7%, and 5.6%, respectively. Therefore, training the BERT model from scratch using the above dataset did not yield the desired results. Consequently, to continue with better performance, it is urging to use a pretrained model to reduce training time and improve the accuracy of predicting the next word during text summarization. This decision led to significant improvements compared to training BERT from scratch. However, due to BERT's limitation in input text length, that will be better when transitioning to another pretrained model called BERT Multilingual. This model has a longer input text length capability than BERT and offers better embedding support. Table II is the result that model achieved in training multiple times.

TABLE II.       THE RESULT OF THE MODEL WITH THE ROUGE 1, ROUGE 2 VÀ ROUGE L

|  | ROUGE-1 | ROUGE-2 | ROUGE-L |
|---|---|---|---|
| Pre-trained BERT and LDA | 0.102 | 0.081 | 0.113 |

## VI.  CONCLUTIONS AND DEVELOPMENT DIRECTIONS

### A. Conclusions

Currently, with the experiment with the BERT model, it seems that the combination of LDA and the BERT model has not achieved the desired effectiveness. The ROUGE-1, ROUGE-2, and ROUGE-L scores have not shown significant improvements, and the generated words do not appear to be highly related to the input text's topic, and the grammar is not as polished as desired, despite the good training results of the LDA model.

Given that the LDA model's results are promising, it is a great idea to consider exploring other language models with the ability to incorporate new features into the model, such as BART. BART is a powerful language model that can be fine-tuned for various natural language processing tasks, including text summarization. It has demonstrated strong performance in abstractive summarization tasks and might provide improvements, especially when combined with LDA. Further experimentation and fine-tuning of this combined approach could yield better results.

### B. Development Directions

Plan for the next step is to continue development based on models that achieve high ROUGE-1, ROUGE-2, and ROUGE-L scores in combination with the LDA model. To diversify the number of topics and ensure equal topic coverage, training an LDA model using deep learning methods is needed. This will enable us to create a model that can predict the topics of text effectively and seamlessly integrate it into state-of-the-art (SOTA) natural language processing models. This approach should help improve the quality and relevance of generated summaries in various applications.

## REFERENCES

[1]   G. Erkan and D. R. Radev, "Lexrank: Graph-based lexical centrality as salience in text summarization," Journal of Artificial Intelligence Research, vol. 22, p. 457-479, Dec 2004.

[2]   R. Nallapati, B. Zhou, C. N. dos santos, C. Gulcehre, and B. Xiang, "Abstractive text summarization using sequence-to-sequence rnns and beyond," 2016.

[3]   K. Papineni, S. Roukos, T. Ward, and W.-J. Zhu, "Bleu: a method for automatic evaluation of machine translation," in Proceedings of the 40th Annual Meeting of the Association for Computational Linguistics, (Philadelphia, Pennsylvania, USA), pp. 311-318, Association for Computational Linguistics, July 2002.

[4]   C.-Y. Lin, "ROUGE: A package for automatic evaluation of summaries," in Text Summarization Branches Out, (Barcelona, Spain), pp. 74-81, Association for Computational Linguistics, July 2004.

[5]   Nguyen Minh, Vu Hoang Tran, Vu Hoang, Huy Duc Ta, Trung Huu Bui, and Steven Quoc Hung Truong. 2022. ViHealthBERT: Pre-trained Language Models for Vietnamese in Health Text Mining. In Proceedings of the Thirteenth Language Resources and Evaluation Conference, pages 328–337, Marseille, France. European Language Resources Association.A. M. Rush, S. Chopra, and J. Weston, "A neural attention model for abstractive sentence summarization," 2015.

[6]   Long Phan, Hieu Tran, Hieu Nguyen, and Trieu H. Trinh. 2022. ViT5:

Pretrained Text-to-Text Transformer for Vietnamese Language Generation. In Proceedings of the 2022 Conference of the North American Chapter of the Association for Computational Linguistics: Human Language Technologies: Student Research Workshop, pages 136–142, Hybrid: Seattle, Washington + Online. Association for Computational Linguistics.Z. Cao, W. Li, S. Li, F. Wei, and Y. Li, "Attsum: Joint learning of focusing and summarization with neural attention," 2016.

[7]  Nguyen Luong Tran, Duong Minh Le, Dat Quoc Nguyen. BARTpho: Pre-trained Sequence-to-Sequence Models for Vietnamese 2022.

[8]  Hamed Jelodar, Yongli Wang, Chi Yuan, Xia Feng, Xiahui Jiang, Yanchao Li, Liang Zhao . Latent Dirichlet Allocation (LDA) and Topic modeling: models, applications, a survey. Dec 2018.

[9]  Telmo Pires, Eva Schlinger, and Dan Garrette. How Multilingual is Multilingual BERT?. In Proceedings of the 57th Annual Meeting of the Association for Computational Linguistics, pages 4996–5001, Florence, Italy. Association for Computational Linguistics. 2019.

[10] Rahul Kumar Gupta, Ritu Agarwalla, Bukya Hemanth Naik, Joythish Reddy Evuri, Apil Thapa, Thoudam Doren Singh , Prediction of research trends using LDA based topic modeling. June 2022.

[11] Jacob Devlin, Ming-Wei Chang, Kenton Lee, Kristina Toutanova. BERT: Pre-training of Deep Bidirectional Transformers for Language Understanding. May 2019

[12] Mykyta Kretinin; Giang Nguyen Topic Modeling on News Articles using Latent Dirichlet Allocation,p. 1543-9259, Oct 2022

[13] P. Anupriya; S. Karpagavalli. LDA based topic modeling of journal abstracts, Nov 2015

# Incorporating Natural Language Processing into Virtual Assistants: An Intelligent Assessment Strategy for Enhancing Language Comprehension

Dr. Franciskus Antonius[1], Purnachandra Rao Alapati[2], Mahyudin Ritonga[3], Dr. Indrajit Patra[4],
Yousef A.Baker El-Ebiary[5], Myagmarsuren Orosoo[6], Manikandan Rengarajan[7]

Lecturer at School of Business and Information Technology STMIK LIKMI, Bandung Indonesia[1]
Associate Professor of English, Prasad V Potluri Siddhartha Institute of Technology,
Kanuru, Vijayawada, Andhra Pradesh, India[2]
Universitas Muhammadiyah Sumatera Barat[3]
An Independent Researcher, PhD from NIT Durgapur, West Bengal, India[4]
Faculty of Informatics and Computing, UniSZA University, Malaysia[5]
School of Humanities and Social Sciences, Mongolian National University of Education, Mongolia[6]
Vel Tech Rangarajan Dr. Sagunthala R&D Institute of Science and Technology, Avadi, Chennai[7]

*Abstract*—The study introduces a comprehensive technique for enhancing the Natural Language Processing (NLP) capabilities of virtual assistant systems. The method addresses the challenges of efficient information transfer and optimizing model size while ensuring improved performance, with a primary focus on model pertaining and distillation. To tackle the issue of vocabulary size affecting model performance, the study employs the SentencePiece tokenizer with unigram settings. This approach allows for the creation of a well-balanced vocabulary, which is essential for striking the right balance between task performance and resource efficiency. a novel pre-layernorm design is introduced, drawing inspiration from models like BERT and RoBERTa. This optimization optimizes the placement of layer normalization within transformer layers during the pretraining phase. Teacher models are effectively trained using masked language modeling objectives and the Deepspeed scaling framework. Modifications to model operations are made, and mixed precision training strategies are explored to ensure stability. The two-stage distillation method efficiently transfers knowledge from teacher models to student models. It begins with an intermediate model, and the data is distilled carefully using logit and hidden layer matching techniques. This information transfer significantly enhances the final student model while maintaining an ideal model size for low-latency applications. In this approach, innovative measurements, such as the precision of filling a mask, are employed to assess the effectiveness and quality of the methods. The findings demonstrate substantial improvements over publicly available models, showcasing the effectiveness of the strategy within complete virtual assistant systems. The proposed approach confirms the potential of the technique to enhance language comprehension and efficiency within virtual assistants, specifically addressing the challenges posed by real-world user inputs. Through extensive testing and rigorous analysis, the capability of the method to meet these objectives is validated.

*Keywords—Natural language processing; virtual assistants; smart evaluation approach; artificial intelligence; human-computer interactions*

## I. INTRODUCTION

Our everyday lives have become more reliant on virtual assistants, which provide efficiency and convenience for a variety of activities, from setting notifications and handling calendars to answering inquiries and managing smart home devices [1]. The capacity of such virtual assistants to understand and interpret user input in natural language is essential to their effectiveness. The core of this language comprehension process is Natural Language Processing (NLP), which enables virtual assistants to comprehend the purpose behind user inquiries and deliver pertinent and contextually suitable replies. Although NLP research has made great strides, conventional virtual assistants frequently have trouble understanding complicated and nuanced user inputs. When their inquiries are incorrectly translated, users may become frustrated, which can result in unsatisfying results and decreased user engagement [2]. These drawbacks highlight the demand for more intelligent and complex methods of language interpretation in virtual assistants. A software programme with artificial intelligence combined with NLP (natural language characteristics are known as a virtual assistant [3]. It acts as a virtual friend that can converse with users in a manner like that of a human and help them with a variety of jobs and enquiries. This technologically advanced system responds to speech or text-based instructions, deciphers user intentions, and offers pertinent data, services, or recommendations in order to expedite and simplify daily tasks [4]. Virtual assistants are becoming a common feature of contemporary digital experiences on a variety of platforms; including computers, smart speakers, wearable technology, and smartphones. These assistants change the way people engage with technology by utilizing NLP to manipulate smart devices, play musical instruments manage appointments, send reminders, obtain weather information, and more [5]. Virtual assistants are anticipated to develop further as artificial intelligence technology progresses, growing better at comprehending context, recognizing individual preferences, and completing difficult

tasks, ultimately changing how we traverse our linked and digital lives.

Virtual assistants' usability and efficacy are greatly influenced by natural language processing (NLP). The manner in which people engage with technology is being revolutionized by these AI-powered assistants' ability to understand, interpret, and reply to human language thanks to NLP [6]. Speech recognition is one of the fundamental elements underlying NLP in virtual assistants, where algorithms translate spoken language into text that can be understood by machines. This allows the assistant to interpret voice instructions. Another crucial element is intent identification, which enables virtual assistants to understand the rationale behind a user's question and tailor their responses. Entity extraction is made easier by NLP, which helps virtual assistants find crucial information in user inputs like places or names [7]. Additionally, NLP empowers virtual assistants to keep track of context during interactions, resulting in more suitable and natural replies. With the ability to generate language, virtual assistants may provide replies that seem human and are customized to the preferences and communication preferences of the user [8]. Sentiment analysis improves the experience by enabling assistants to recognize and understand user emotions. Additionally, NLP offers multilingual assistance, serving a variety of user bases globally. A few virtual assistants also use machine learning algorithms with NLP characteristics for continuous learning, improving their language comprehension and replies over time in response to user input. Virtual assistants' usefulness has been greatly enhanced by the addition of NLP, which makes interactions more natural, individualized, and conversational. Virtual assistants are anticipated to become increasingly smarter as NLP technology develops, interpreting complicated questions and providing contextually appropriate replies that meet the individual needs of users [9].

SEA for understanding language basics marks a significant advancement in the fields of artificial intelligence and natural language processing. The capacity of robots to understand the subtleties of human language is an essential hurdle in today's world when technology is ingrained more deeply into our everyday lives. To meet this problem, the SEA emerged as a revolutionary approach that makes use of current developments in machine learning to get beyond the drawbacks of traditional language understanding techniques. Modern technology is based on language understanding, which enables smooth interactions between humans and machines [10]. Traditional methods, however, frequently fail to adequately capture the subtleties of language, setting, and purpose. By fusing context analysis, entity extraction, and intelligent intent identification into one seamless framework, the SEA makes a brave step forward. By doing this, it not only aims to improve the sensitivity and accuracy of language processing devices but it additionally presents the possibility of reshaping user experiences in a variety of sectors [11]. The SEA has the ability to fundamentally alter the design of virtual assistant systems. These AI-powered friends have become an essential part of our lives, assisting us with everything from managing calendars to operating smart gadgets. Involving SEA, virtual assistants will be able to go beyond what they are now capable of, increasing the breadth of their understanding and raising the quality of their relationships with users. The main goal of SEA is to close the gap between computer interpretation and the subtleties of human language, therefore enabling more intuitive and natural communication. The SEA's importance goes beyond only technology. The SEA equips virtual assistants to act as knowledgeable guides, expertly leading users throughout a large sea of data in the age of overload of information and rapid technological advancement [12]. The SEA not only increases efficiency but also creates the foundation for establishing trust between people and computers by allowing virtual assistants to comprehend contextual and user intent more precisely. This study intends to give a thorough analysis of the Smart Evaluation Approach's methodology, implementation tactics, and the intriguing research directions it opens upon our delve into its complexities. By combining artificial intelligence and natural language processing, SEA aims to reinvent the fundamentals of language understanding, pushing the limits of what virtual assistants can accomplish and fundamentally altering how we engage with technology [13].

The study presents a Smart Evaluation Approach (SEA) that aims to improve virtual assistants' ability to understand language. The SEA uses new developments in artificial intelligence and machine learning to address problems with traditional virtual assistants. The SEA seeks to greatly improve virtual assistants' accuracy and response to user inputs using intelligent intent identification, entity extraction, and contextual analysis. The study's major goal is to expand the capabilities of virtual assistants' existing language understanding techniques in order to promote more intuitive and natural human-machine interactions. A thorough assessment of the literature on NLP, AI, virtual assistants, and comprehension of language approaches is part of the paper's framework. The conceptual framework for the virtual assistant network and its integration with SEA are then discussed, followed by the approach used for SEA installation and assessment. The merits and possible improvements of the suggested technique are highlighted by the detailed experimental results and comparison analysis with conventional approaches [14]. The conclusion summarizes the research findings and suggests new avenues of inquiry for improving language comprehension in virtual assistants. The goal of using NLP and the smart assessment method is to unlock the potential of virtual assistants, alter technology engagement, and enable smooth and efficient human-machine communication. The key contributions of the research models are as follows:

- This study focuses on enhancing Natural Language Understanding (NLU) capabilities in a large-scale virtual assistant through language model pretraining and distillation techniques, specifically targeting intent classification and slot filling, which are critical components of effective language comprehension.

- The research addresses the challenge of understanding user intentions and identifying relevant slots in user inputs. For instance, given a query like "can you call mom," our NLU model should discern the intention to

initiate a call and identify the corresponding slot, in this case, the contact's name, marked as "mom".

- Throughout the paper, the research consistently refers to our models and pipeline as "Virtual Assistant Teacher Model(s) (VATM)". This nomenclature reflects the unique aspects of our problem domain, which diverges from traditional research tasks in several ways.

- This approach leverage relatively extensive labeled datasets, which is noteworthy as it introduces challenges and opportunities distinct from typical pretraining approaches.

- The research emphasizes the importance of optimizing model efficiency, as our models must operate within stringent latency and memory limitations, ensuring their practical utility in real-world scenarios.

- Research tackle the unique challenge of processing primarily spoken language data, distinguishing our work from the more common "written form" text used in the pretraining of publicly available models.

This system's capability extends across multiple languages, adding an additional layer of complexity to the language understanding process. The study tackles the intricate challenge of improving language understanding within virtual assistants by leveraging language model pretraining and distillation techniques. We navigate through unique challenges, including a sizable labeled dataset, performance constraints, spoken language input, and multilingual support, to enhance the overall NLU capabilities of our Virtual Assistant Teacher Models (VATMs).

## II. RELATED WORKS

Ait-Mlouk and Jiang [15] introduces "KBot", a novel ChatBot designed to harness the power of knowledge graphs and linked data for enhancing natural language understanding. With the increasing availability of structured data in the form of knowledge bases on the semantic web, the objective of the ChatBot is to make this information accessible and beneficial for end-users. The authors address several challenges associated with building such a ChatBot, including user query comprehension, support for multiple knowledge bases, and multilingual capabilities. The authors present an architecture that facilitates an interactive user interface, enabling effective communication between users and the ChatBot. They propose a machine learning-based approach that employs intent classification and natural language understanding to interpret user intents and generate SPARQL queries for retrieving relevant information from knowledge bases. Notably, the authors extend their system by incorporating a new social network dataset, 'myPersonality,' into existing knowledge bases, enhancing the ChatBot's ability to handle analytical queries. The system allows for the incorporation of new domains, offers flexibility in supporting multiple knowledge bases, and is designed to handle multilingual interactions. The paper also emphasizes the user-friendly creation and execution of various tasks across a broad spectrum of topics. The paper supports its claims with evaluation and application cases that demonstrate KBot's practical utility. These examples underscore how the ChatBot effectively navigates semantic data to cater to diverse real-world scenarios. The approach taken by the authors is particularly notable for its data-driven nature, leveraging knowledge graphs to provide insightful responses. The paper makes a significant contribution to the field of natural language processing and knowledge graph utilization. KBot's architecture and machine learning-based approach, along with its demonstrated adaptability and practical application, position it as a valuable tool for interactive and data-rich interactions.

Jungbluth et al. [16] delves into the integration of popular virtual assistants like Alexa, Siri, Cortana, and Google Assistant with industrial robotics, focusing on their role in controlling components of an intelligent robot assistant system for disassembly tasks. The authors introduce the paper by highlighting the increasing presence of virtual assistants in daily life, particularly their use as intuitive human-machine interfaces for device control through natural language. The core contribution of the work lies in its exploration of using virtual assistants to manage individual elements within a sophisticated industrial robot assistance system. After a succinct introduction and a survey of available virtual assistants, the authors present their system architecture, which seamlessly incorporates Amazon's Alexa using an Echo Dot device. Leveraging the Alexa Skills Kit, they develop a voice user interface encompassing various device functionalities and assistive behaviors. The authors detail the technical setup, which involves linking Alexa Voice Service with Amazon's Lambda and IoT web services. This connectivity facilitates the customization of machine commands based on users' voice inputs. Through intermediary components like a Raspberry Pi, they establish communication between the internet and the robot's isolated network. A notable aspect is the bidirectional communication flow, enabling real-time updates of device statuses in Amazon Web Services IoT shadow. This status information is subsequently utilized in Lambda functions to generate speech output using Alexa Voice Services and relayed through the Echo Dot for user notifications. The conclusion offers a balanced perspective by highlighting both positive and negative experiences encountered during their endeavors. The paper provides a comprehensive case study of integrating virtual assistants, particularly Amazon's Alexa, into the realm of industrial robotics. The technical details, architecture overview, and demonstration of a use case collectively exemplify the potential benefits and challenges of combining virtual and robot assistants. The work underscores the practicality of leveraging virtual assistants in complex real-world scenarios and contributes to the growing understanding of their integration within industrial applications.

Alagha and Helbing [17] responses to consumer health questions about vaccines: an exploratory comparison of Alexa, Google Assistant and Siri" aims to assess and compare the accuracy and quality of responses provided by Amazon Alexa, Google Assistant, and Siri to consumer health queries regarding vaccine safety and usage. The study employs a rubric-based scoring system to evaluate the responses of each voice assistant across 54 questions related to vaccination. The

evaluation criteria include the accuracy of the answer given through audio output and the credibility of the source supporting the response. The findings of the study reveal significant differences in the performance of the three voice assistants. Siri obtains the highest average score of 5.16 points, followed closely by Google Assistant with an average score of 5.10 points. In contrast, Alexa lags behind with a notably lower average score of 0.98 points. The results indicate that Google Assistant and Siri excel in accurately interpreting voice queries and providing users with authoritative sources of information about vaccination. However, Alexa struggles to comprehend queries and relies on sources different from those used by the other two assistants. The authors conclude that those involved in patient education should be cognizant of the varying quality of responses provided by different voice assistants. They also suggest that developers and health technology experts should advocate for improved usability and transparency in terms of information partnerships as these devices continue to evolve in their capabilities to deliver health-related information. The article is available under the Creative Commons Attribution Non Commercial (CC BY-NC 4.0) license, permitting others to share, adapt, and build upon the work non-commercially, provided appropriate credit is given, changes are indicated, and usage remains non-commercial. The study contributes valuable insights into the performance of voice assistants in delivering accurate and reliable health information to users. The findings underscore the importance of further refining these technologies to ensure consistent and high-quality responses, especially in critical domains such as health information dissemination.

Villegas-Ch et al. [18] explores the implementation of a virtual assistant for managing academic aspects within a university using artificial intelligence (AI). In light of the ongoing pandemic, private universities are encountering challenges across academic and financial domains. Learning difficulties have contributed to increased dropout rates, exacerbating financial strains. Additionally, economic impacts from the pandemic have led to a decline in students seeking private education. These circumstances necessitate support measures to enhance student enrollment, safeguard budgets, and optimize resources. The academic realm poses significant efforts to manage academic activities while prioritizing those interested in pursuing educational programs. To address these complex challenges, integrating technologies like Chatbots, powered by artificial intelligence, emerges as a solution. By leveraging AI-powered Chatbots, universities can delegate tasks such as providing information about academic courses. This offloads administrative burdens and simultaneously enhances the user experience, thereby encouraging greater participation in the university community. The integration of AI-powered Chatbots can offer multifaceted benefits. These tools can efficiently handle information dissemination about academic courses, freeing up human resources for more critical tasks. They contribute to a smoother and more engaging user experience, potentially attracting more prospective students. This technology aligns well with the broader trend of digital transformation in education, offering personalized and immediate support to users. However, it's important to consider the potential challenges and limitations of implementing such systems. Ensuring accurate and contextually relevant responses, maintaining data privacy, and addressing potential technical glitches are areas that require careful attention. The paper underscores the need for private universities to adapt to the current circumstances by embracing technological solutions like AI-driven Chatbots. These tools hold the promise of enhancing student enrollment, reducing administrative burdens, and ultimately improving the overall efficiency and effectiveness of academic management in the face of evolving challenges.

Dong et al. [19] provides a brand-new method called the Universal pre-trained linguistic model (UniLM), which is intended to handle both responsibilities of comprehending and producing natural language. Utilizing A Transformer network that is shared among multiple users goes through pre-training utilizing a variety of language modeling tasks, including unidirectional, bidirectional in nature, and sequence-to-sequence prediction, this is accomplished. Specific self-awareness masks are used to identify the pertinent context for predictions to achieve unified modeling. On the frequently utilized GLUE measure as well as on challenging tasks including SQuAD 2.0 and CoQA problem answering, UniLM performs favorably when compared to BERT. The study demonstrates how UniLM outperforms industry standards on five naturally language-generating datasets. The ROUGE-L scores for CNN/DailyMail abstract summarization and Gigaword abstractive summarizing both saw increases of 2.04 absolute points and 0.86 absolute points, respectively, reaching 40.51 and 35.75, respectively. UniLM makes major advancements in generative question-answering tasks in addition to summarization. It produces an astounding 82.5 per cent increase in the F1 score with CoQA generating question answering. Additionally, the article documents significant gains in the DSTC7 document-grounded dialogue answer generating NIST-4 rating (achieving 2.67, with individual performance at 2.65), as well as the SQuAD controversy generating BLEU-4 score (3.75 absolute enhancements, reaching 22.12). The article proposes UniLM, a brand-new unified already trained linguistic model that performs very well on challenges requiring both interpretation and creation of natural language. The algorithm's superiority over current state-of-the-art models and outstanding performance on numerous benchmarks and datasets emphasize its potential to enhance the study of the processing of natural language. The research approach and conclusions in this work provide a substantial contribution to the creation of more powerful and adaptable language representations for use in real-world situations.

An overview of the main points, benefits, and drawbacks of the relevant papers are provided in the Table I. While having trouble with language support and user query comprehension, Ait-Mlouk and Jiang [15] employ natural language processing and machine learning-based intent categorization, utilising knowledge graphs to deliver perceptive responses. In order to overcome the hurdles involved in this integration, Jungbluth et al. [16] incorporate Amazon's Alexa with industrial robot support systems for real-time communication. Voice assistants' answers to health-related questions are compared using a rubric-based rating

system by Alagha and Helbing [17], exposing differences in response quality. Chatbots driven by AI are used by Villegas-Ch et al. [18] to improve administrative effectiveness and information distribution in higher education. The Universal pre-trained linguistic model (UniLM), as introduced by Dong et al. [19], improves F1 scores and natural language generation performance on multiple benchmarks in natural language processing tasks.

TABLE I.        OVERALL SUMMARY OF LITERATURE REVIEW

| Reference | Technique | Merits | Limitation |
|---|---|---|---|
| Ait-Mlouk and Jiang [15] | Natural language processing and intent classification powered by machine learning. | Applying knowledge graphs to provide perceptive answers and integrating other data areas | Difficulties with language support, multiple knowledge base support, and user query comprehension. |
| Jungbluth et al. [16] | Integration of Amazon's Alexa into industrial robot assistance systems, technical setup, and real-time communication. | Integration of popular virtual assistants like Alexa into industrial robotics, offering a use case in industrial applications. | Challenges associated with the integration of virtual assistants into industrial robotics and practical use cases in the real world. |
| Alagha and Helbing [17] | Rubric-based scoring system to evaluate the responses' accuracy and credibility. | Comparative assessment of Amazon Alexa, Google Assistant, and Siri in responding to health | Differences in the quality of responses provided by voice assistants to consumer health queries. |
| Villegas-Ch et al. [18] | Integration of AI-powered Chatbots to handle information dissemination and streamline administrative tasks. | Improved distribution of information regarding educational programs, increased efficiency, and an enhanced user experience within the context of higher education. | Leveraging AI-driven Chatbots for the administration of academic functions in privately-owned educational institutions. |
| Dong et al. [19] | Development of the Universal pre-trained linguistic model (UniLM) using shared Transformer networks, self-awareness masks, and pre-training using language modeling tasks. | Enhancements in performance across diverse natural language generation tasks, such as summarization and question-answering, resulting in impressive F1 scores and leading outcomes on various evaluation benchmarks. | Introducing the Universal pre-trained linguistic model (UniLM) for natural language processing (NLP) assignments. |

## III.    PROBLEM STATEMENT

The domain of virtual assistant systems faces a substantial challenge in achieving both efficiency and accuracy in language understanding. Striking the right balance between model size and performance is paramount, particularly for applications that require low-latency responses. However, the current landscape is marked by models that tend to be overly large, leading to latency and resource constraints, or simplified versions that sacrifice language understanding capabilities [20]. The evaluation of these models poses significant challenges, particularly with regard to the limitations of conventional metrics like perplexity, which can be influenced by tokenization choices and may not accurately reflect real-world performance. Existing evaluation methods may not fully capture the intricacies of language comprehension necessary for virtual assistant tasks that involve precise understanding and response to user intents and slots. Therefore, the central challenge is to develop an approach that distills knowledge from larger models into smaller ones while either preserving or enhancing their language understanding capabilities. This involves addressing the delicate balance between reducing model size and maintaining performance standards. Innovative evaluation metrics are essential to align with the specific requirements of virtual assistants, offering a comprehensive gauge of language understanding quality. The ultimate goal is to establish a robust methodology that tackles the dual challenges of model efficiency and performance, while introducing novel evaluation techniques tailored to the demands of real-world virtual assistant applications. Successfully addressing this challenge promises the development of highly efficient yet accurate language understanding models, ultimately revolutionizing virtual assistant technology and elevating user experiences across a wide range of domains, including customer service and personal assistants.

## IV.    PROPOSED METHODOLOGY FOR EVALUATION OF LANGUAGE UNDERSTANDING

The methodology employed in this study follows a comprehensive approach to enhance language understanding capabilities. The process starts with the selection of diverse pretraining datasets, including the multilingual Colossal Clean Common Crawl (mC4), CC100 dataset, and Wikipedia data. These datasets encompass various domains, languages, and tones. Incorporating twelve languages for pretraining, such as Arabic, English, French, and more, establishes a robust foundation for multilingual comprehension. The sampling process, guided by a multinomial distribution, ensures proportional representation of languages while up-sampling low-resource ones. Preprocessing involves organizing sentences into sequences and dynamic tokenization during training. Additionally, a Stage 2 pretraining dataset, comprising anonymized utterance text from the system, undergoes refinement through duplication reduction, length filtering, and integration with public datasets. Tokenization strategy employs a SentencePiece tokenizer with intrinsic metrics, optimizing vocabulary size for effective tokenization. During pretraining, a modified architecture, introducing pre-layernorm components, aids in capturing both intra- and inter-sentence structures. Stage 2 pretraining focuses on enhancing

the model's specialization for virtual assistant utterances. Distillation techniques are applied in two phases, with an intermediate-sized model distilled from the large teacher model, followed by the use of this distilled model as a teacher

for the final, smaller student model. Validation leverages the "mask-filling accuracy" task to monitor progress and performance.
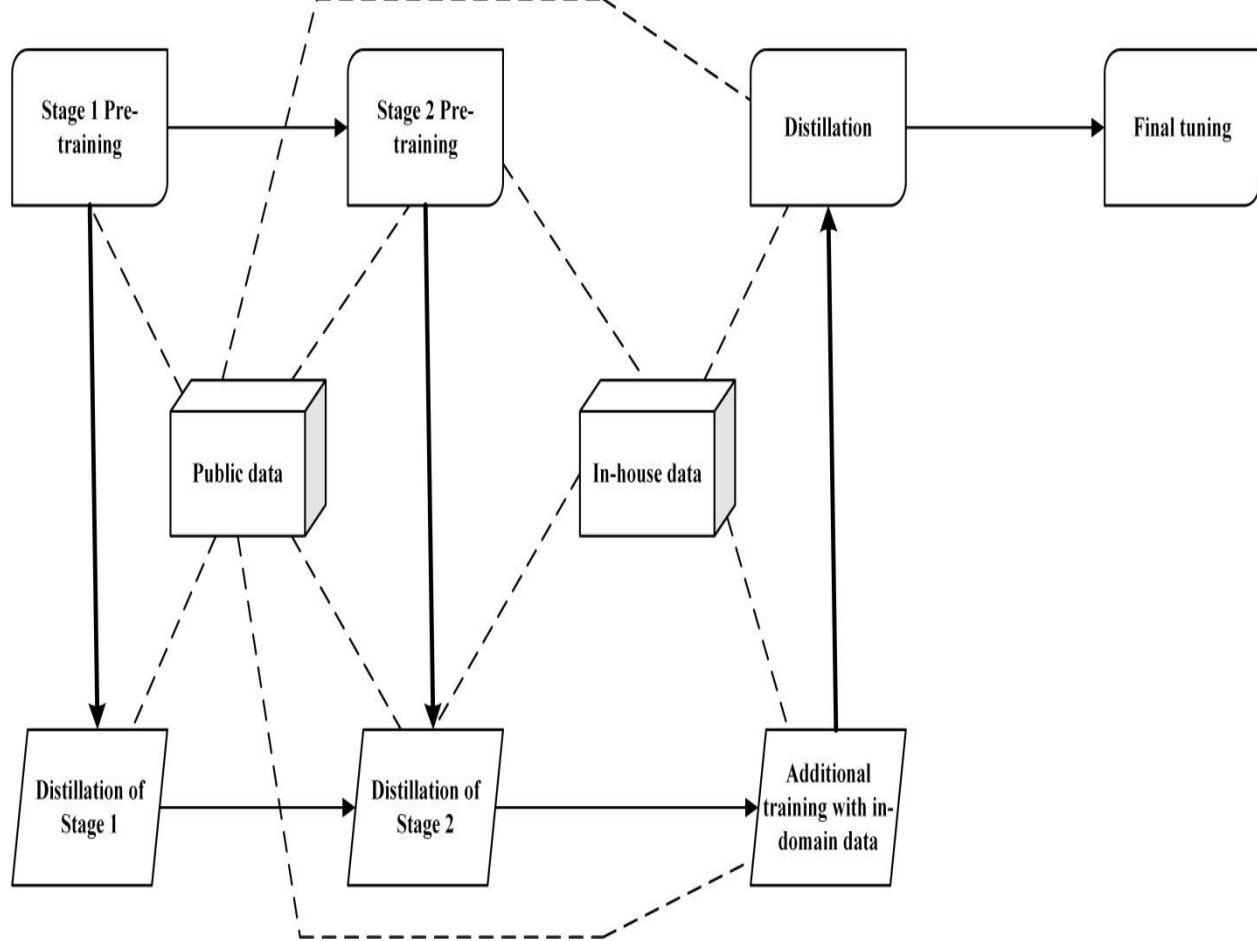


Fig. 1. Proposed model training and evaluation framework.

### A. Training Datasets

Pre-training datasets, which include a wide variety of data covering different areas, zones, languages, and more, are an essential basis for improving language processing abilities. This study takes into account a trio of primary sources of pre-training data: Wikipedia data, which helped train BERT, mBERT, and the BooksCorpus; the multiple-language Colossal Clean Common Crawl (mC4) a database, used for T5 and mT5 training; the CC100 a database, used to instruct XLM-R. Notably, Common Crawl data are used to create the mC4 and CC-100 datasets. A systematic strategy was used for selecting phrases from the training corpus, which included twelve languages for pre-training: the language of Arabic, English, French, German, Italian, Japanese, Marathi, Portuguese, Spanish, Tamil, and Telugu are all examples of supported languages. To ensure representation across languages, phrases were chosen for sampling using a multinomial distribution in accordance with predetermined rules. By up-sampling countries with fewer examples, the selection procedure, which was controlled by a multinomial distributing equation, aimed to achieve a balance. This

technique successfully improved low-resource languages, resulting in a more varied dataset.

TABLE II. DATASET

|  | Section 1 | Section 2 | Section 3 |
|---|---|---|---|
| data to Train | 95K | 84 K | 70 K |
| Validation data set | 15K | 12 K | 20 K |
| Size of test data | 25K | 24 K | 40 K |
| # of intents | 17 | 9 | 15 |
| # of slots | 97 | 28 | 58 |

Table II provides an overview of the dataset used for training, validation, and testing in the context of our language understanding model. The dataset is divided into three distinct domains, each representing a different aspect or category of language understanding.

The preprocessing method improved the dataset's quality. Sentences were organized into sequences of about 700 words,

and dynamic tokenization was carried out while training. This method made sure that sequences stayed inside the 1,024-token limit after tokenization while maintaining sequence integrity. In addition to publicly available datasets, a private Stage 2 prior instruction dataset made up of unlabeled and anonymous utterance text was included. There were several preparation stages for this dataset. Instances with lesser than five tokens were deleted, and duplicates have been minimized by keeping just a portion of their original total. In order to create an exhaustive collection for Stage 2 pretraining, this private data was pooled in a 1:2 ratio with the open Stage 1 pretraining database to reduce catastrophic forgetting. In the end, our efforts produced a Stage 2 pretraining database with over 50 million cases. These datasets were smoothly included in the training pipeline that was developed, as shown in Fig. 1. The need of creating a thorough and comprehensive pretraining database to improve language comprehension models is highlighted by this method of data collecting, curation, and preparation [21].

### B. Text Pre-processing using Tokenization

This approach revolves around the application of a SentencePiece tokenizer trained in the unigram setting, with the aim of enhancing Natural Language Processing within the realm of Virtual Assistants. The vocabulary size of the tokenizer emerged as a pivotal factor impacting the overall system performance. While larger vocabulary sizes often yield performance improvements in tasks like masked language modeling, they also introduce trade-offs, such as slower training convergence, heightened memory consumption during inference, and increased latency. Considering the resource-intensive nature of training an extensive teacher model with a wide-ranging tokenizer vocabulary, we introduced two intrinsic tokenizer metrics: the split-ratio and unk-token fraction. These metrics enabled us to meticulously balance performance and resource utilization without necessitating protracted teacher model training. The split ratio metric, grounded in the principle that a higher count of subword splits can compromise overall accuracy, guided our optimization efforts. Meanwhile, the unk-token fraction metric, which gauges the prevalence of unknown tokens in output, emerged as a pivotal performance determinant. A higher proportion of unk-token fractions negatively impacted the overall system performance. To align our tokenizer's split-ratio and unk-token fraction with baseline production models, we strategically incorporated an extensive set of 2,136 frequently used kanji characters in Japanese. This set was complemented by a comprehensive array of hiragana and katakana symbols, thus ensuring robust coverage of Japanese characters. Our strategy also involved partitioning data in a 70/30 ratio between spoken and written forms. This discerning distribution facilitated the attainment of a balanced vocabulary size, ultimately totaling 150,000 subword tokens. This vocabulary size was in harmony with the effective approach adopted in our pretraining corpus strategy. The foundation of our methodology for integrating Natural Language Processing capabilities into Virtual Assistants centers on a sophisticated SentencePiece tokenizer, meticulously trained in the unigram setting. The intrinsic tokenizer metrics, namely the split-ratio and unk-token fraction, were harnessed to strike a harmonious equilibrium between task performance and efficient resource

utilization. Additionally, the thoughtful incorporation of diverse Japanese characters ensured comprehensive language coverage. This astute evaluation approach is poised to elevate language comprehension within the domain of Virtual Assistants.

### C. Stage 1 and Stage 2 Pre-training Model

In the initial pre-training phase, we drew inspiration from established models like BERT, RoBERTa, and XLM-R to shape our approach. While our Virtual Assistant models found their foundation in RoBERTa, a distinct innovation emerged through the implementation of pre-layernorm architecture. This architectural adjustment involved placing layer normalization immediately before the self-attention and feed-forward blocks within each transformer layer. Central to this training process was the masked language modeling objective, where 15% of tokens within the text were masked. Among these masked tokens, 10% were maintained unchanged, while an additional 10% were substituted with random tokens. Our teacher models underwent training with a focus on scalability, culminating in the management of up to 9.3 billion non-embedding parameters. To enhance training throughput, the Deepspeed framework came into play, capitalizing on its two-stage strategy. In the first stage, optimizer states were distributed across GPUs, followed by gradient partitioning in the second stage. Notably, this was executed without introducing network-based bottlenecks. Employing mixed precision training was pivotal in optimizing computational efficiency. This technique enabled us to achieve an impressive computational output of 107 TFLOP/sec per GPU for an encoder housing 9.3 billion parameters. Our infrastructure was grounded in AWS p4d.24xlarge instances, housing Nvidia a100 GPUs and leveraging Elastic Fabric Adapters to ensure steadfast network throughput. Throughout the pretraining journey, Deepspeed's mixed precision training mechanism remained our companion. Nonetheless, some model operations encountered challenges related to FP16 overflow. To address these concerns, two key modifications were introduced. Firstly, the baddbmm operation took the place of the matmul operation for query-key multiplication. Secondly, a conversion to FP32 was performed before variance computation during the layer normalization process. These changes, while slightly decreasing throughput by up to 20%, successfully mitigated instability issues within the model. It's worth noting that an alternative avenue to handle stability concerns entails the utilization of BFLOAT16. However, this path wasn't available within the Deepspeed framework during our experimentation phase. Transitioning to Stage 2 pretraining, our exploration delved into the Muppet system. Unlike the initial phase, Stage 2 pretraining employed a more direct approach. We extended the pretraining objective using our designated Stage 2 dataset. The primary objective here was to enhance the model's proficiency in handling virtual assistant-specific utterances, which are often brief and may deviate from strict grammatical norms. A careful balance was sought between enhancing specialized capabilities and retaining the broader language knowledge gained during Stage 1.

### D. Distillation

Given the imperative of modest model sizes for low-latency applications, a direct distillation from extensively

large teacher models to considerably smaller student models might hinder the effective transfer of the teacher's expertise. As a remedy, a two-stage teacher assistance setup was devised for the distillation process, as illustrated in Fig. 1. This strategy aimed to strike a balance between knowledge transfer and model size reduction. In the initial stage, the immense teacher model was compressed into an intermediate-sized model. Subsequently, the final student model was trained using this intermediate model as a guide. This approach ensured that the transfer of knowledge from the teacher to the student was well-optimized, despite the significant size reduction. Drawing inspiration from the teacher's pretraining methodology, a distillation process was initiated from a randomly initialized student model. Convergence in training signaled a seamless transition to the deployment of the Stage 2 teacher model, thus continuing the distillation process. Importantly, the data employed for distillation in both stages remained consistent with the data utilized for teacher pretraining in their respective stages. Within the intermediate student/teacher pairing, a balanced blend of categorical cross-entropy (MLM loss) and soft cross-entropy was applied, with equal weighting. Remarkably, experimentation indicated no substantial benefits from incorporating the attention and hidden layer outputs of the teacher model. Transitioning to the final student model, a dual-stage process was undertaken. First, the intermediate model underwent further pretraining, exclusively using Stage 2 data and without teacher involvement. Subsequently, a distillation procedure was executed to seamlessly transfer knowledge to the compact final student model. During this distillation phase, techniques mirrored those employed in the initial distillation, with the addition of hidden-layer output matching. In essence, the approach mirrors the core principles of the process outlined in the source paper. The process ensures effective knowledge transfer while mitigating the challenges arising from substantial model size reductions.

### E. Validation of Model Performance without Fine-Tuning

In order to effectively monitor the progress of our training efforts, a commonly employed technique is evaluating perplexity on a separate validation dataset. However, a notable drawback of perplexity measurements is their susceptibility to the tokenizer's specific characteristics. To overcome this limitation, this study introduced an innovative evaluation metric called "mask-filling accuracy", designed to enhance the comparability of different models. The formulation of these metric involved curating texts from diverse public tasks, encompassing resources like XNLI, PAWS-X, and Multi-lingual Amazon Reviews. It is worth noting that we deliberately excluded these specific examples from our training dataset. For each instance within this curated dataset, we leveraged the Stanza tagger to identify a noun word. Subsequently, all subword tokens corresponding to that noun were concealed. The model's task was to accurately predict all subword tokens associated with the hidden noun, with successful predictions deemed correct. A notable insight, highlighted in Fig. 2 and 3, reveals a robust correlation

between perplexity measurements and mask-filling accuracy, as well as the model's performance on the XNLI benchmark. This correlation persists across various stages of model updates. This finding underscores the valuable potential of our mask-filling accuracy metric as a reliable indicator of model quality. Importantly, this metric transcends the challenges introduced by the nuances of different tokenization approaches. This novel approach to validating model performance without fine-tuning presents promising insights. It serves as an effective means of assessing the quality of models, bypassing the inherent limitations posed by tokenizer choices. This strategy, as outlined in the original paper, holds promise for similar applications in various contexts.

## V. RESULT AND ANALYSIS

Analysis of the performance and effectiveness of language understanding models within the realm of virtual assistant systems. Our exploration was underpinned by a meticulous evaluation process, which encompassed multiple stages and methodologies, ultimately yielding insightful results and findings. First, we investigated the relationship between XNLI accuracy and perplexity, as well as mask-filling accuracy, using the approach of a 2.3 billion parameter model. This analysis was crucial for understanding the interplay between these metrics and their correlation with model performance over various updates. Notably, we observed that the mask-filling accuracy exhibited a stronger correlation with XNLI accuracy during the no-fine-tune validation process, indicating its potential as a more informative gauge of model quality, less susceptible to the intricacies of tokenization choices. Moving forward, the approach focused on the evaluation of our distilled models in comparison to publicly available models, utilizing comprehensive training datasets specific to our system. Our assessment involved benchmarking against XLM-R Base with 85 million non-embedding parameters and the multilingual DistillBERT with 42 million non-embedding parameters. Notably, our distilled models consistently outperformed the public models in terms of exact match error rate. Most promisingly, our compact 17 million-parameter model demonstrated a remarkable 4.23% improvement over XLM-R, while retaining its performance margin over our larger 170 million-parameter model, showcasing an improvement of 4.82% over XLM-R. In the pursuit of holistic evaluation, we delved into the performance of our models within the full framework of a virtual assistant system. To accomplish this, an intermediate-sized model with 170 million non-embedding parameters acted as a teacher-assistant to distill the final student models. This compression journey involved multiple stages of distillation, leveraging diverse datasets and employing logit matching and hidden layer matching techniques. Our models underwent extensive testing via parallel A/B testing and sequential testing, simulating real-world scenarios. These evaluations encompassed automated measures of user dissatisfaction, particularly tail dissatisfaction, and the offline Semantic Error Rate (SemER) that evaluates intent and slot-filling performance.
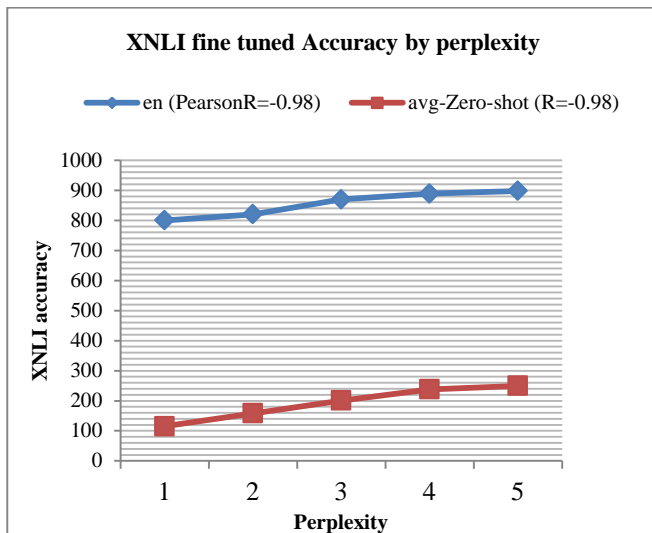
Fig. 2.    XNLI accuracy from perplexity.
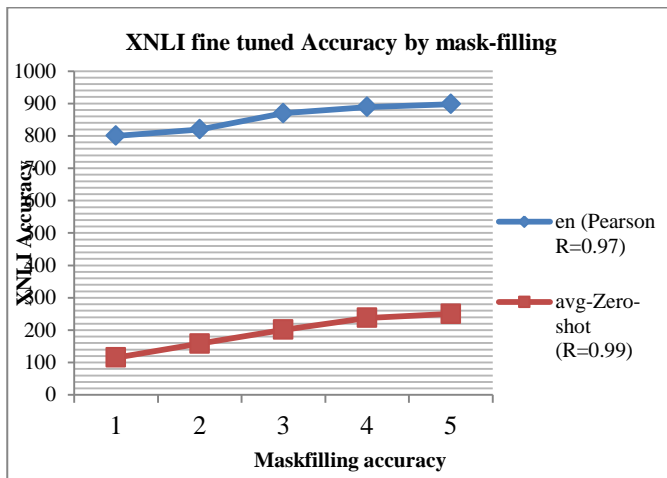


Fig. 3.    XNLI accuracy as of mask-filling accuracy.

Fig. 2 and Fig. 3 utilizing the approach of 2.3Bparameter model, the relationship between XNLI accuracy and perplexity, as well as mask-filling accuracy, are being studied over model updates. The measure performs better for no-fine-tune validation the higher the correlation.

### A. NLU Results following Distillation

Our evaluation involved comparing the performance of our distilled models against publicly available models, using the complete training datasets specific to our system, as detailed in Section 3.4. The considered public models encompass XLM-R Base, featuring 85M non-embedding parameters, and the multilingual DistillBERT, comprising 42M non-embedding parameters. For an example to be counted as an

exact match, the model must correctly predict both the intent and all associated slots. Encouragingly, both of our distilled models exhibit superior performance compared to the public models on average. Our 17M-parameter model, which shows an enhancement of 4.83% over XLM-R while showing only little decline when compared to our 170-M-parameter version (an increase of 4.63% over XLM-R), is particularly notable.

### B.  Full System Results

This research follows the design described in Section 2.6 to provide a thorough evaluation of the model's effectiveness within the context of a whole virtual assistant system. The teacher assistant for the distillation of the final student models is an intermediate-sized model with 170M non-embedding parameters. This intermediate model underwent many steps of compression, including 160K entries of distillation from a 700M-parameter first-phase teacher, 105K updates from the Phase 1 2.3B-parameter teacher, and 300K updates from the second Stage 2 2.3B-parameter model. Further details on hyperparameters for the 700M-parameter model can be found in Appendix A. The 170M-parameter model, post fine-tuning with a task-specific dataset for 15,625 updates, acted as the teacher for distilling 17M-parameter student models. Distillation employed logit matching and hidden layer matching, following the student-teacher layer mapping (0, 1, 2, and 3) to (3, 7, 11, 15). Optimal performance emerged from utilizing two checkpoints within the same 17M-parameter model distillation process: one after 80M examples and the other after 200M examples. This process involved the inclusion of 9 languages: English, French, German, Hindi, Italian, Marathi, Spanish, Tamil, and Telugu. Two baseline models, each constituting a 5M-parameter monolingual encoder distilled from a BERT-Base architecture teacher, were considered. These baselines employed Wikipedia dumps in the relevant languages, following the text conversion to spoken form. Our comprehensive study occurred within a virtual assistant system experimentation platform. Our models were subjected to both parallel A/B testing, involving distinct user cohorts, and sequential testing with the same user cohort. The assessment encompassed automated measures of user dissatisfaction across the entire virtual assistant system, alongside considerations for tail dissatisfaction (related to less common utterances). The offline Semantic Error Rate (SemER) evaluations were conducted, jointly evaluating intent and slot-filling performance. SemER considers correct slots, deletion errors, insertion errors, and substitution errors, along with intent classification errors. The methodology employed aligns with the foundational principles outlined in the original paper. Our approach showcases promising potential for effectively assessing model performance within the intricate landscape of virtual assistant systems.

$$SemER = \frac{\text{\# Deletion} + \text{\# Insertion} + \text{\# Substitution}}{\text{\# Correct} + \text{\# Deletion} + \text{\# Substitution}} \qquad (1)$$

The 2.3B-parameter Phase 2 model, the distilled 170-M-parameter Phase 2 model, and the 17-M-parameter Phase 2 model were assessed The results are shown in Tables III and IV, respectively. A negative number implies a lower error rate compared to the Stage 1 baseline model with 2.3B parameters.

TABLE III.    FULL FINE-TUNING

| Complete-fine-tuning | | | |
|---|---|---|---|
| Reduced Relative-Intent-Class-Error Versus 2.3-B Phase 1 | | | |
| | *Section 1* | *Section 2* | *Section 3* | *Average* |
| 2.3-B Phase -2 | -4.72% | -1.78% | -6.79% | -2.76% |
| 170-M from 2.3-B | -3.28% | -3.98% | -2.36% | -1.97% |
| 17-M from 170-M | 10.56% | 9.78% | 9.75% | 9.98% |
| Reduced Relative-Slot-Filling-Error Versus 2.3-B Stage 1 | | | |
| | *Section 1* | *Section 2* | *Section 3* | *Average* |
| 2.3-B Phase-2 | -6.02% | -10.05% | -6.68% | -8.01% |
| 170-M from 2.3-B | -1.62% | -11.03% | -9.53% | -9.68% |
| 17-M from 170-M | 28.07% | 3.11% | 4.36% | 11.51% |

TABLE IV.    FROZEN-ENCODER RESULTS

| Frozen Encoder | | | |
|---|---|---|---|
| Improvement of the Relative-Intent-Class-Error Versus 2.3B Stage 1 | | | |
| | *Section* 1 | *Section* 2 | *Section* 3 | Average |
| 2.3-B Phase-2 | -11.61% | -4.61% | -2.78% | -6.98% |
| 170-M from 2.3-B | -16.09% | -17.23% | -12.09% | -16.70% |
| 17-M from 170-M | 12.99% | 7.49% | 11.89% | 11.78% |
| Improvement in Relative-Slot-Filling-Error Versus 2.3B Stage 1 | | | |
| | *Section* 1 | *Section* 2 | *Section* 3 | Average |
| 2.3-B Phase-2 | -5.56% | -18.98% | -5.79% | -9.31% |
| 170-M from 2.3-B | -6.17% | -11.93% | -2.90% | -6.99% |
| 17-M from 170-M | 18.46% | -6.90% | 2.90% | 5.01% |

TABLE V.    RESULTS FROM A PLATFORM FOR TESTING VIRTUAL ASSISTANTS

| | Experiment 1 | Experiment 2 |
|---|---|---|
| *Non-Embed Base Teacher Parameters* | 85-M | 85-M |
| *FF Size, Hidden Size, and Base Layers* | 4/312/1200 | 4/312/1200 |
| *Non-Embed Base Parameter Count* | 5-M | 5-M |
| *Support for Base Langs* | 1 | 1 |
| *Non-Embedded Parameters for Cand Teachers* | 2.3-B | 2.3-B |
| *Non-Embed Parameters for Cand Teachers* | 170-M | 170-M |
| *FF Size, Hidden Size, and Cand Layers* | 4/768/1200 | 4/768/1200 |
| *Non-Embed Cand Params* | 17-M | 17-M |
| *Cand Langs was backed* | 9 | 9 |
| *Cand Distil Illustrations* | 80-M | 200-M |
| *Testing Position* | 1 | 2 |
| *Entire Solution User Discontent A/B* | -3.74% | -4.91% |
| *Tail A/B for Entire Solution User discontent* | -10.3% | -7.50% |
| *Users' Overall discontent Score* | -14.9% | -7.2% |
| *Inactive SemER* | -15.6% | -2.98% |

In Table V, the findings presented are from two different experiments (Exp) carried out in distinct locations using a virtual assistant experimentation platform comparing our 17-M-parameter candidate model (Cand) is compared to the reference model (Base), which was developed by an 85-M-parameter teacher using Wikipedia data. Relative findings from an A/B test conducted concurrently with a distinct user cohort and an alternating test conducted using identical users are both shown for the computerized metric of whole-system user discontent. The tail A/B results from utterances beyond of the top 500 are also presented.

### C. Discussion

The presented findings and outcomes from the performance evaluation of language comprehension models in the context of virtual assistant systems represent a meticulous and thorough investigation of these models. In order to maximise the utility of these models for practical applications, this research emphasizes the complex nature of the fine-tuning and distillation processes [22]. The study started by exploring the connection between XNLI accuracy, perplexity, and mask-filling accuracy, offering insightful information about how these metrics relate to model performance across various updates [23]. Notably, the mask-filling accuracy showed strong model quality indicators, especially in the absence of fine-tuning, indicating its potential as a more accurate performance indicator that goes beyond tokenization intricacies. As the evaluation progressed, the emphasis shifted to evaluating the performance of the distilled models against publicly accessible models. The distilled models consistently outperformed public models in the assessment, especially in terms of exact match error rate, which took into account a variety of parameters, including non-embedding parameters. Particularly, the compact 17 million-parameter model showed striking improvements over reference models, demonstrating the possibility of developing more effective and efficient models in the context of virtual assistants. The research expanded its evaluation to take into account the overall performance of these models within the more general framework of a virtual assistant system, moving beyond model-centric assessments. This required using multiple datasets, logit matching, and hidden layer matching techniques in a multi-stage distillation process.

In order to simulate real-world situations and gauge user dissatisfaction, particularly for less frequent utterances, the evaluation included parallel A/B testing and sequential testing in addition to the offline Semantic Error Rate (SemER), which assesses intent and slot-filling performance [23]. The outcomes of these studies showed concrete advantages, with decreases in relative intent-class error and slot-filling error compared to baseline models, highlighting the efficiency of the distillation process in improving model performance within the complex environment of virtual assistant systems. User dissatisfaction scores significantly decreased for both the system as a whole and for less frequent utterances, highlighting the tangible enhancements in the user experience. This study offers a thorough and organized assessment of language comprehension models in the context of virtual assistant systems. The results point to a promising development in the development of virtual assistants and their

function in enhancing human-machine interactions: the approach of fine-tuning and distillation can result in more effective, accurate, and user-friendly models.

The full virtual assistant system analyses that, our analysis showcased the comprehensive assessment we conducted. An intermediate-sized model with 170 million non-embedding parameters served as a teacher-assistant, distilling final student models. Our multi-stage approach to distillation, which involved leveraging diverse datasets and employing logit matching and hidden layer matching techniques, showcased the effectiveness of knowledge transfer from teacher to student models [24]. These distilled models were extensively tested using both parallel A/B testing and sequential testing, simulating real-world scenarios. The evaluations encompassed measures of user dissatisfaction across the entire virtual assistant system, particularly focusing on less common utterances (tail dissatisfaction), as well as the Semantic Error Rate (SemER) that evaluates intent and slot-filling performance. The study provides a comprehensive and nuanced understanding of how distilled models perform within the intricate landscape of virtual assistant systems. By addressing challenges related to model size reduction, evaluating performance across various metrics, and testing in real-world usage scenarios, our findings contribute to advancing language understanding technology and optimizing virtual assistant systems for enhanced user experiences.

### D. Challenges and Limitation

A prominent field of research and development is integrating Natural Language Processing (NLP) into virtual assistants since it has the potential to significantly improve these systems' functionality. The current approaches to NLP in virtual assistants, however, have drawbacks and limitations, just like any other technology. Here are some of these difficulties and restrictions:

*1) Challenges:* Natural language presents a significant problem due to its inherent ambiguity and reliance on context. Virtual assistants frequently have trouble understanding the complexities of context, which causes them to misread user requests. This restriction may make it more difficult to have natural discussions and give accurate responses. Another issue is support for several languages [25]. Virtual assistants powered by NLP must be proficient in a variety of languages, each with its own distinctive quirks. For users who speak uncommon languages or participate in multilingual conversations, some may fare very well in one language but fall short in others. For a flawless user experience, real-time processing is necessary. Nevertheless, NLP processing can be computationally demanding, making it difficult to provide immediate or close to real-time solutions [26]. This lag time may irritate users and lessen virtual assistants' general efficacy. Additionally, the difficulty of generalisation looms big. Many virtual assistants struggle to infer knowledge from certain user interactions. Instead, they might rely too heavily on pre-programmed reactions, which would make it harder for them to adjust to different user needs and would lessen their overall value. For virtual assistant technology to advance,

these problems must be solved. The improvement of NLP models, contextual understanding, multilingual support, real-time processing, implementation of strong privacy safeguards, and creation of more generalised and adaptable virtual assistants should be the main areas of research and development. These initiatives will assist NLP be more successfully and conveniently incorporated into virtual assistant technologies.

*2) Limitations:* Virtual assistants' dearth of common-sense reasoning is a key drawback. Their inability to participate in truly natural conversations is hampered by their frequent inability to comprehend fundamental, daily concepts and situations. When customers expect their virtual assistants to understand basic, contextual questions, this shortcoming might result in unsatisfactory and fragmented interactions. Another difficulty is managing lengthy talks. During lengthy conversations, context can be lost by existing NLP models, leading to responses that do not fit the general direction of the discourse. When consumers converse with virtual assistants in-depth or complex topics, this shortcoming may become especially apparent. Misinformation vulnerability is a serious issue, particularly in industries like news or healthcare. If virtual assistants don't have the tools to check the veracity of the information they provide, they might unintentionally spread harmful information or make false claims [27].

Virtual assistants might also have knowledge gaps in specific fields. When asked questions about specialized topics or industries, NLP models might not have current or in-depth knowledge, which results in answers that are incorrect or lacking. This restriction may limit the usefulness of virtual assistants in work-related or contexts requiring in-depth knowledge. Creating and maintaining NLP-driven virtual assistants can be prohibitively expensive and resource-intensive [28]. This restriction may make it difficult for smaller organizations and underserved communities to access this technology, potentially resulting in a digital divide. Another difficulty is the complexity and expense of integrating NLP into current systems. Because of this complexity, it may be challenging for businesses and organizations to adopt these technologies without major time and resource commitments. Continuous research and development efforts are crucial to overcoming these constraints and difficulties. This entails enhancing the capacity for common-sense reasoning, boosting the capacity for lengthy conversations, putting in place fact-checking procedures to thwart false information, honing domain-specific knowledge, and reducing response bias [29].

## VI. Conclusion and Future Prospect

This research offers a comprehensive approach to enhancing language understanding models within the realm of virtual assistant systems. Through a carefully structured series of experiments and in-depth analyses, we have substantiated the effectiveness of distilled models in achieving remarkable performance levels while upholding model efficiency. A noteworthy aspect of our findings lies in the recognition of the pivotal role played by meticulous evaluation metrics,

particularly highlighting the superiority of metrics like mask-filling accuracy over conventional perplexity measurements. This innovation enhances the robustness and practical relevance of our evaluation methods in real-world applications. The results of our study also showcase the significant advantages of the distillation process. By carefully compressing large teacher models into intermediate-sized models, the successful transferred knowledge while overcoming challenges posed by model size reduction. Our distilled models consistently outperformed publicly available models, proving the efficacy of our approach in producing models that are not only more efficient but also more accurate in language understanding tasks. This has direct implications for the development of high-performing virtual assistant systems that can deliver prompt and accurate responses to user queries.

Looking forward to the research opens the door to exciting future prospects in the field of language understanding and virtual assistants. The success of our distillation process encourages further exploration into optimization techniques that can balance model size and performance. Additionally, the innovative evaluation metrics we introduced, such as mask-filling accuracy, offer new directions for evaluating model quality, which can be refined and extended in future studies. As virtual assistant systems continue to evolve, the insights from our research can guide the development of more efficient and effective models. The demonstrated techniques for distillation and evaluation provide a foundation for building even more advanced systems that can understand and respond to user input with increased accuracy and speed. As technology progresses, our work lays the groundwork for continuous improvements in virtual assistant capabilities, ultimately enhancing user experiences and interactions. The presented study contributes valuable knowledge to the field of language understanding in virtual assistant systems, offering practical solutions for optimizing model efficiency and performance. As the field continues to evolve, our research provides a strong stepping stone for future innovations that will shape the way virtual assistants understand and interact with users.

## References

[1] C. Lee, Y. Ko, and J. Seo, "A Simultaneous Recognition Framework for the Spoken Language Understanding Module of Intelligent Personal Assistant Software on Smart Phones," in Proceedings of the 53rd Annual Meeting of the Association for Computational Linguistics and the 7th International Joint Conference on Natural Language Processing (Volume 2: Short Papers), Beijing, China: Association for Computational Linguistics, 2015, pp. 818–822. doi: 10.3115/v1/P15-2134.

[2] A. P. Sam, B. Singh, and A. S. Das, "A Robust Methodology for Building an Artificial Intelligent (AI) Virtual Assistant for Payment Processing," in 2019 IEEE Technology & Engineering Management Conference (TEMSCON), Atlanta, GA, USA: IEEE, Jun. 2019, pp. 1–6. doi: 10.1109/TEMSCON.2019.8813584.

[3] J. Luketina et al., "A Survey of Reinforcement Learning Informed by Natural Language," 2019, doi: 10.48550/ARXIV.1906.03926.

[4] M. Dzikovska, N. Steinhauser, E. Farrow, J. Moore, and G. Campbell, "BEETLE II: Deep Natural Language Understanding and Automatic Feedback Generation for Intelligent Tutoring in Basic Electricity and Electronics," Int J Artif Intell Educ, vol. 24, no. 3, pp. 284–332, Sep. 2014, doi: 10.1007/s40593-014-0017-9.

[5] H. Mahmoudi, S. Camboim, and M. A. Brovelli, "Development of a Voice Virtual Assistant for the Geospatial Data Visualization

Application on the Web," Computer Science and Mathematics, preprint, Jul. 2023. doi: 10.20944/preprints202307.0413.v1.

[6] G. Dizon, "Evaluating intelligent personal assistants for L2 listening and speaking development," Feb. 2020, Accessed: Aug. 10, 2023. [Online]. Available: http://hdl.handle.net/10125/44705

[7] A. Mishakova, F. Portet, T. Desot, and M. Vacher, "Learning Natural Language Understanding Systems from Unaligned Labels for Voice Command in Smart Homes," in 2019 IEEE International Conference on Pervasive Computing and Communications Workshops (PerCom Workshops), Kyoto, Japan: IEEE, Mar. 2019, pp. 832–837. doi: 10.1109/PERCOMW.2019.8730721.

[8] E. Elshan, P. Ebel, M. Söllner, and J. M. Leimeister, "Leveraging Low Code Development of Smart Personal Assistants: An Integrated Design Approach with the SPADE Method," Journal of Management Information Systems, vol. 40, no. 1, pp. 96–129, Jan. 2023, doi: 10.1080/07421222.2023.2172776.

[9] A. Hodorog, I. Petri, and Y. Rezgui, "Machine learning and Natural Language Processing of social media data for event detection in smart cities," Sustainable Cities and Society, vol. 85, p. 104026, Oct. 2022, doi: 10.1016/j.scs.2022.104026.

[10] Z. Yang, L. Shou, M. Gong, W. Lin, and D. Jiang, "Model Compression with Two-stage Multi-teacher Knowledge Distillation for Web Question Answering System," in Proceedings of the 13th International Conference on Web Search and Data Mining, Houston TX USA: ACM, Jan. 2020, pp. 690–698. doi: 10.1145/3336191.3371792.

[11] J. Mariani, S. Rosset, M. Garnier-Rizet, and L. Devillers, Eds., Natural Interaction with Robots, Knowbots and Smartphones: Putting Spoken Dialog Systems into Practice. New York, NY: Springer New York, 2014. doi: 10.1007/978-1-4614-8280-2.

[12] J. R. Bellegarda, "Spoken Language Understanding for Natural Interaction: The Siri Experience," in Natural Interaction with Robots, Knowbots and Smartphones, J. Mariani, S. Rosset, M. Garnier-Rizet, and L. Devillers, Eds., New York, NY: Springer New York, 2014, pp. 3–14. doi: 10.1007/978-1-4614-8280-2_1.

[13] C. Lee and Y. Ko, "Spoken Language Understanding with a Novel Simultaneous Recognition Technique for Intelligent Personal Assistant Software," Int. J. Artif. Intell. Tools, vol. 27, no. 03, p. 1850009, May 2018, doi: 10.1142/S0218213018500094.

[14] W. Hariri, "Unlocking the Potential of ChatGPT: A Comprehensive Exploration of its Applications, Advantages, Limitations, and Future Directions in Natural Language Processing," 2023, doi: 10.48550/ARXIV.2304.02017.

[15] A. Ait-Mlouk and L. Jiang, "KBot: A Knowledge Graph Based ChatBot for Natural Language Understanding Over Linked Data," IEEE Access, vol. 8, pp. 149220–149230, 2020, doi: 10.1109/ACCESS.2020.3016142.

[16] J. Jungbluth, K. Siedentopp, R. Krieger, W. Gerke, and P. Plapper, "Combining Virtual and Robot Assistants—A Case Study about Integrating Amazon's Alexa as a Voice Interface in Robotics," 2018.

[17] E. C. Alagha and R. R. Helbing, "Evaluating the quality of voice assistants' responses to consumer health questions about vaccines: an exploratory comparison of Alexa, Google Assistant and Siri," BMJ Health Care Inform, vol. 26, no. 1, p. e100075, Nov. 2019, doi: 10.1136/bmjhci-2019-100075.

[18] W. Villegas-Ch, J. García-Ortiz, K. Mullo-Ca, S. Sánchez-Viteri, and M. Roman-Cañizares, "Implementation of a Virtual Assistant for the Academic Management of a University with the Use of Artificial Intelligence," Future Internet, vol. 13, no. 4, p. 97, Apr. 2021, doi: 10.3390/fi13040097.

[19] L. Dong et al., "Unified Language Model Pre-training for Natural Language Understanding and Generation," 2019.

[20] M. Syromiatnikov and V. Ruvinskaya, "Natural Language Processing for Intelligent Virtual Assistant System," 2020.

[21] J. FitzGerald et al., "Alexa Teacher Model: Pretraining and Distilling Multi-Billion-Parameter Encoders for Natural Language Understanding Systems," in Proceedings of the 28th ACM SIGKDD Conference on Knowledge Discovery and Data Mining, Washington DC USA: ACM, Aug. 2022, pp. 2893–2902. doi: 10.1145/3534678.3539173.

[22] M. U. Hadi et al., "Large Language Models: A Comprehensive Survey of its Applications, Challenges, Limitations, and Future Prospects." TechRxiv, Sep. 21, 2023. doi: 10.36227/techrxiv.23589741.v3.

[23] J. FitzGerald et al., "Alexa Teacher Model: Pretraining and Distilling Multi-Billion-Parameter Encoders for Natural Language Understanding Systems," in Proceedings of the 28th ACM SIGKDD Conference on Knowledge Discovery and Data Mining, in KDD '22. New York, NY, USA: Association for Computing Machinery, Aug. 2022, pp. 2893–2902. doi: 10.1145/3534678.3539173.

[24] H. B. Essel, D. Vlachopoulos, A. Tachie-Menson, E. E. Johnson, and P. K. Baah, "The impact of a virtual teaching assistant (chatbot) on students' learning in Ghanaian higher education," International Journal of Educational Technology in Higher Education, vol. 19, no. 1, p. 57, Nov. 2022, doi: 10.1186/s41239-022-00362-6.

[25] K. Affolter, K. Stockinger, and A. Bernstein, "A comparative survey of recent natural language interfaces for databases," The VLDB Journal, vol. 28, no. 5, pp. 793–819, Oct. 2019, doi: 10.1007/s00778-019-00567-8.

[26] M. Hagiwara, Real-World Natural Language Processing: Practical applications with deep learning. Simon and Schuster, 2021.

[27] J. Anderson and L. Rainie, "The Future of Truth and Misinformation Online," Pew Research Center: Internet, Science & Tech. Accessed: Oct. 25, 2023. [Online]. Available: https://www.pewresearch.org/internet/2017/10/19/the-future-of-truth-and-misinformation-online/

[28] A. Piñeiro-Martín, C. García-Mateo, L. Docío-Fernández, and M. del C. López-Pérez, "Ethical Challenges in the Development of Virtual Assistants Powered by Large Language Models," Electronics, vol. 12, no. 14, Art. no. 14, Jan. 2023, doi: 10.3390/electronics12143170.

[29] Read "How People Learn II: Learners, Contexts, and Cultures" at NAP.edu. doi: 10.17226/24783.

# A Novel Multidimensional Reference Model for Heterogeneous Textual Datasets using Context, Semantic and Syntactic Clues

Ganesh Kumar[1], Shuib Basri[2], Abdullahi Abubakar Imam[3],
Abdullateef Oluwagbemiga Balogun[4], Hussaini Mamman[5], Luiz Fernando Capretz[6]
Computer and Information Sciences Department (CISD), Universiti Teknologi PETRONAS,
Bdr Sri Iskandar, 32610 Seri Iskandar, Perak, Malaysia[1, 2, 4, 5]
School of Digital Sciences, Universiti Brunei Darussalam, BE1410, Brunei Darussalam[3]
Department of Electrical and Computer Engineering Western University, London, Canada[6]

*Abstract*—With the advent of technology and use of latest devices, they produce voluminous data. Out of it, 80% of the data are unstructured and remaining 20% are structured and semi-structured. The produced data are in heterogeneous format and without following any standards. Among heterogeneous (structured, semi-structured and unstructured) data, textual data are nowadays used by industries for prediction and visualization of future challenges. Extracting useful information from it is really challenging for stakeholders due to lexical and semantic matching. Few studies have been solving this issue by using ontologies and semantic tools, but the main limitations of proposed work were the less coverage of multidimensional terms. To solve this problem, this study aims to produce a novel multidimensional reference model using linguistics categories for heterogeneous textual datasets. The categories in such context, semantic and syntactic clues are focused along with their score. The main contribution of MRM is that it checks each tokens with each term based on indexing of linguistic categories such as synonym, antonym, formal, lexical word order and co-occurrence. The experiments show that the percentage of MRM is better than the state-of-the-art single dimension reference model in terms of more coverage, linguistics categories and heterogeneous datasets.

*Keywords—Reference model; computational linguistics; heterogeneous data; context clues; semantic clues; syntactic clues*

## I. INTRODUCTION

"Big Data" refers to data sets with sizes beyond the ability of commonly used software tools to capture, curate, manage, and process data within a tolerable elapsed time. Various industries with heterogeneous data are facing problems related to storing, managing, retrieving, and analyzing of large amount of data. Big Data plays an important role in retrieving useful information from the large datasets with the help of advanced tools and algorithms [1]. Nowadays, data produced in formats such as structured, semi-structured and unstructured data from a multidimensional nature of resources and applications that cannot be processed through simple tools [2].

In general, Big Data can be explained according to three V's: Volume, Velocity and Variety [3]. Also, the other characteristics of Big Data described in [4] are volume, variety, velocity, veracity, valence, and value. Later on, in [5] 10V's

volume, variety, velocity, veracity, variability, viscosity, volatility, viability, validity, and value are exposed.

In Big Data Variety, the heterogeneous types of data formed, and it further classified in three types namely, Structured, Semistructured and Unstructured (SSU) [6], [7]. Structured data is organized data in a predefined format and stored in tabular form whereas semi-structured data is a form of data which cannot be queried as it does not have a proper structure which confers to any data model and unstructured data is heterogeneous and variable in nature such as text, audio, video, and images. Due to heterogeneous data, it cannot be processed with simple tools and techniques which create the problem heterogeneity and similarity matching [2] in result, decision maker cannot make decision based on scattered data.

With the advent of the technology, the computers are nowadays used to retrieve the linguistics information from textual data which is known as Computational Linguistics (CL) [8]-[9]. CL is classified into many categories but among them context clues, semantic, and syntactic [9]-[11] matching is widely used in the domain of linguistics. CL helps in identifying and matching of related words from input datasets with the data dictionary which is known as domain knowledge [12].

The domain knowledge further known as reference model (RM) have been used in the field of NLP and semantic-lexical matching. Vasilieous et al. in [13]–[15] proposed a single dimensional reference model (SRM) for medical data quality of textual dataset. The SRM only matches one token to one term at a time and it was developed for structured dataset whereas the same patient's data can be represented in other forms of terms. Also, in other formats (semi-structured or unstructured). Therefore, this paper proposes a multidimensional reference model (MRM) for one token to many terms matching and as well as for heterogeneous datasets.

The concept of multidimensional reference was adopted from [16]-[17], in which different schemas for one to one and one to many queries for NoSQL Injection were proposed as well in [20]-[21]

The aim of this study is to solve the requestion question i.e. How to build a context, semantic and syntactic based reference model for more data inclusivity? Which can be achieved through this research objective i.e., to develop a multidimensional reference model (MRM) based on context, semantic and syntactic bag of words for a better data inclusivity. The significance of this research is to measure the inclusivity of Semantic, context and syntactic words in MRM.

For further understanding about multidimensional reference model for heterogeneous textual datasets this paper is organized as follows: Section II and III describe the related work and methodology adopted for creating the MRM and experiments conducted on heterogeneous datasets, Section IV presents the results for heterogeneous datasets while Section V discusses the results and Section VI and Section VII presents the conclusion and future work respectively.

## II. RELATED WORK

Ordinarily, the reference model works as a procedure that contains the domain knowledge and relevant indexing of a topic or information of interest. It works as a common template for structured data that contains a set of parameters which are important for generating the domain knowledge [14].

The proposed multidimensional reference model as shown in Fig. 8. It comes with extra features to handle heterogenous datasets. It uses a generalized natural language concept and domain knowledge which helps the input datasets in selection of appropriate multidimensional domain data. Multidimensional indexing is also an added technique which classifies linguistic words into context, semantics, and syntactic clues.

These three categories aim to assist in building the vocabulary and understanding the domain knowledge with respect to meaning, structure and representation of words as opposed to the existing reference models where the selection of terms is solely based on one-to-one relationship (see Fig. 1).
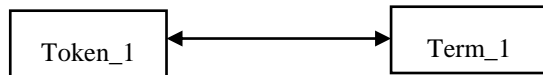


Fig. 1. Existing reference model method.

It can be observed from Fig. 1 that the relationship is one-to-one. Meaning, for any given token, a corresponding match term is retrieved from the reference model. This selection is based on threshold values to identify the best matching term in the corpus. The term with the highest value is selected as a candidate for data curation.

On the contrary, the proposed multidimensional reference model utilizes a multifaceted concept as depicted in Fig. 2 below. Basically, the MRM checks the relationship between the token and its related term in multiple dimensions in order to identify the most appropriate term as shown in Fig. 2 and Fig. 8 (Appendix A)
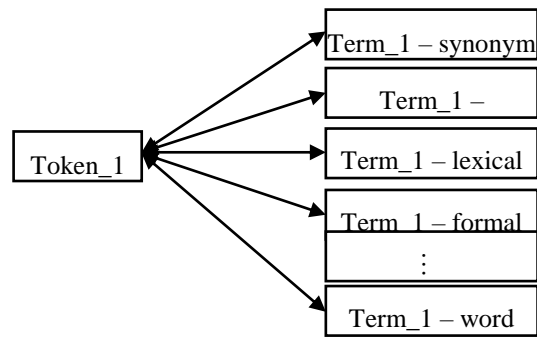


Fig. 2. Proposed multidimensional reference model core concept.

As illustrated in Fig. 8 (Appendix A), we can see that a token from the input dataset is matched with its potential related term in several dimensions such as synonym [18], semantic, lexical [19], etc. For instance, a token "bank" could score high when matched with a term "boundary", which means the edge of a river. However, if the lexical matching of same word is conducted, a financial institution, or storage may be flagged off. Therefore, it's very important to view one token in different dimensions. This will significantly increase the accuracy of terms matching at different levels of data harmonization.

The categories mentioned in MRM are context clue, semantic and syntactic. Context clues are further classified into synonym and antonym. Sample words and their score are presented in Appendix C and D. The second and most important category used in MRM for indexing the linguistics words is semantics. It plays a vital and significant role in understanding the information related to datasets.

As mentioned earlier, the first type of semantic clue is formal semantics which uses techniques such as logic, philosophy, and math to analyze data within the relationship of language and reality, truth, and possibility. The list of words and their score can be found in Appendix E and F.

The third and last category of MRM is syntactic clue which focuses on the word order and co-occurrences. In order to identify patterns amongst data points (words), the order and co-occurrences are adopted and implemented. The list of words for both the order and co-occurrences is offered in Appendix G and H.

It's important to highlight here clearly that the categories of MRM such as contextual, semantic, and syntactic clues and their score (as shown in Appendix C-H) helped in developing the multidimensional (indexed based) reference model. The MRM provides the input to the section that performs the data harmonization process. The section contains terminology extraction, rules definition, lexical matching and semantic matching which are responsible for producing data harmonization report and harmonized dataset.

## III. METHODOLOGY

For development of multidimensional reference model, following four steps have been taken (i) defining the generated tokens (ii) identifying the root word (iii) Determining the dimensions (iv) aggregating the dimensions root word. These steps are also shown in the Fig. 3.
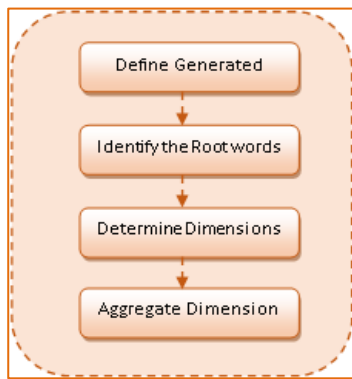
Fig. 3.    Steps carried out for MRM development.

Among five datasets, the ACE2020 dataset is XLS (structured) format which contains the information about labeled text news produced and recorded at different news agencies. The dataset comprises of 621 news of different categories. Whereas Aquaint dataset is in TXT (Unstructured) format which contains 50 different news produced in diverse nature and rich in information. This dataset comprises of 729 lines. On the other hand, Sarcasm headline dataset is JSON (semi-structured) format which also contains the information about the news headline. This dataset comprises of 26709 lines. All datasets are purchased by LDC organization for research purpose.

In step one, the tokens are generated from heterogeneous datasets. The input datasets contain news of the daily life including sarcasm (keys and values). Participating datasets are in structured (Xls), semi-structured (JSON) and unstructured (Txt). After preprocessing the input datasets, structured dataset is formed which have been used for token generation.

In second step the root words are identified based on the generated tokens. In the third and fourth steps the determining the dimensions and aggregating them into categories of root words are formed. As stated above, the indexing scheme of dimension follows the concept of one-to-one and one-to-many cardinalities from SQL.

For implementation of MRM, research was carried out on the MMR development stages (see Fig. 3.). The experiment aimed to assess the performance of MRM. A single workstation was used for the experiments. It housed the following specifications: GPU: NVIDIA Tesla P100 12GB Passive GPU, CPU: Intel Xeon E5-2620 v4 2.1GHz, 32 cores, 128GB RAM, 800GB SSD, 1GB bandwidth ethernet card, and windows operating system. Textual datasets with numerous characteristics and sizes of 75KB, 150KB, and 10MB are employed. For performance evaluation, Anaconda and Python 3.7.3 are installed on the workstation along with Jupyter notebook, pandas, NumPy, matplotlib, and orange3 libraries.

Based on the root words and dimensions of MRM, the most common words using the linguistics words categories are retrieved and named as mrm_words. It contains the mrm_score() which will help in DH.

Validations of results (MRM with SRM) are discussed in following section.

## IV.  RESULTS

The proposed Multidimensional Reference Model (MRM) was developed using linguistic word categories i.e., context, semantic and syntactic clues. The main aim of developing MRM is to improve the quality of terms-matching by referring to the target terms in different dimension. This is achieved with the help of indexed based domain knowledge to root-words/tokens. Indexing is generated and classified using synonyms, antonyms, lexical semantics, formal semantics, word-order, and co-occurrence.

Each word has its respective score (mrm_score()) that is empirically assigned which helps in matching terms based on defined rules, semantic, and lexical matching. The total number of words generated from linguistic word categories (i.e., context, semantic and syntactic clues) for MRM repository is 37321.

The performance of proposed MRM with existing single dimensional reference model (SRM) is compared and presented in this section. Five different heterogeneous datasets namely, ACE 2020, Aquaint, Sarcasm, HUA, and UoA are implemented on both SRM and MRM in order to obtain a justifiable conclusion on which reference model is actually better. It's important to mention here that SRM was implemented in a similar comparison on two out of the five aforementioned datasets (i.e., HUA and UoA). This indicates that our comparison is more rigorous in nature as it covers all data structures (heterogenous, to be precise).

The experiment was conducted five times (Batch 1-5) for each dataset. Batch 1 utilizes 20% of each dataset, and continuously increases 20% for the subsequent batches until 100% of each dataset is tested. This is done for both MRM and SRM to evaluate their individual performances. The batches and their respective data distributions are explained in Error! Reference source not found. The Table I (Appendix B) shows the results of the experiments conducted on MRM which presents total terms of input datasets, total matched terms with MRM and percentage of matched terms.

In order to evaluate the performance of best reference models on participating datasets, the experiments are conducted on five different batches of datasets as presented in (Appendix B). The two collaborating reference models are tested five different times for each variable. After that an average of scores for five round is taken and compared, the results of each round are presented separately. Figure Error! No text of specified style in document.1 illustrates the results of round one in which a comparison between the MRM and SRM for total terms and matched terms are discussed.

Fig. 4 depicts a significant result of the round 1 for all participating datasets using SRM and MRM. On left of the figure, the results of existing SRM and on the right the results of proposed MRM are shown. The first set of analysis begins with performance of SRM on participating datasets. Initially, 2564 terms of ACE2020 were tested on SRM, out of which 1212 were matched successfully. Secondly, 2192 terms of Aquaint dataset were examined, out of which only 551were matched. Similarly, 5740 terms of Sarcasm dataset were tested out of which merely 1198 were matched. Subsequently, 16

terms of UoA dataset were examined on SRM, out of which 15 were matched. Lastly, the 12 terms for HUA were tested and out of which 11 were matched. The results show a variation in matching of terms with the use of SRM, but it performed well on the UoA and HUA datasets.
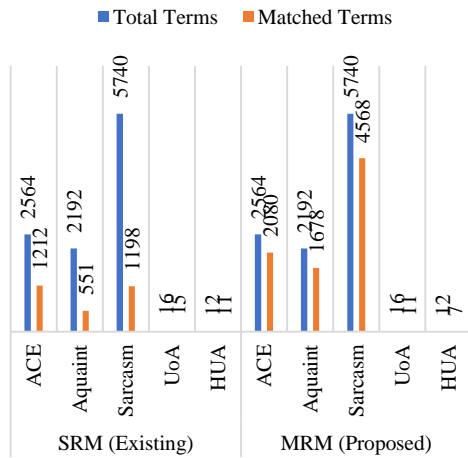


Fig. 4.    Number of succesfully matched terms for MRM and SRm on batch 1.

On the other hand of analysis, the input datasets are used to test the performance of MRM. At first, 2564 terms of ACE2020 were tested on MRM, out of  which 2080 were matched magnificently. Subsequently, 2192 terms of Aquaint dataset were examined, out of which only 1678 were matched well. Similarly, 5740 terms of Sarcasm dataset were tested out of which 4568 were matched perfectly. Afterwards, 16 terms of UoA dataset were examined on MRM, out of which 11 were matched. Last of all, the 12 terms for HUA were tested and out of which seven were matched.



| | ACE | Aqua int | Sarca sm | UoA | HUA |
|---|---|---|---|---|---|
| SRM | 47.27 | 25.14 | 20.87 | 93.75 | 91.67 |
| MRM | 81.12 | 76.55 | 79.58 | 68.75 | 58.33 |
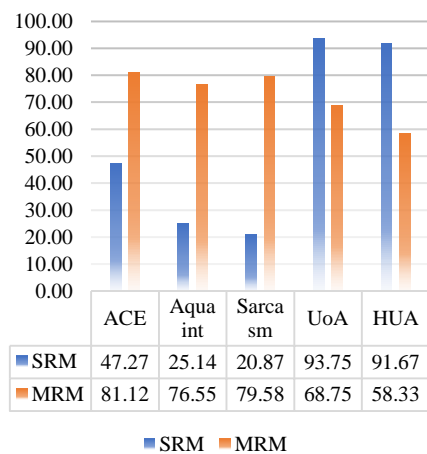
Fig. 5.    Percentage of matched terms for MRM and SRM on batch 1.

The performance findings from this round suggest that the MRM performed better than SRM on ACE 2020, Aquaint and Sarcasm datasets whereas the SRM works better on HUA and

UoA datasets. Fig. 5 illustrates the terms matched (in terms of matched percentage) with both reference models on participating datasets.

The percentage of matched terms using SRM for ACE2020, Aquaint, Sarcasm, UoA and HUA are 47%, 25%, 20%, 93% and 91%, respectively. Whereas the percentage of matched terms using MRM for ACE2020, Aquaint, Sarcasm, UoA and HUA are 81%, 76%, 79%, 68% and 58%, respectively. This is because the proposed MRM covers multiple dimensions such as context, semantic and syntactic clues. One of the significant contributions of MRM is that it checks each participating word/token from input dataset with index based domain knowledge.

With that, the input tokens are checked multiple times and based on the context and similarity score of the index it produces very similar words. It is worth  noting that if any of the tokens' score is high based on the similarity, but the score is less in terms of context than the terms which matched based on the context are selected. Whereas the existing SRM only checks the similarity based on string and lexical similarity and only in single dimension.

Comparative analysis on the results of SRM and MRM shows that the performance of MRM is better than the SRM on ACE 2020, Aquaint and Sarcasm datasets while the SRM performs better on HUA and UoA datasets. The results of MRM on UoA and HUA datasets are low which is due to different domain knowledge (medical) of the datasets. In Fig. 6, the performance of SRM and MRM are measured for batch 5 on contributing datasets. The remaining batches (2-4) are not presented here but the average of all five batches is presented in Table I. (Appendix B).

A significant result of the round five for all participating datasets using SRM and MRM. On left of the figure, the results of existing SRM and on the right the results of proposed MRM are shown. The first set of analysis begins with performance of SRM on participating datasets. Initially, 12820, terms of ACE2020 were tested on SRM, out of  which 5605 were matched successfully. Secondly, 10960 terms of Aquaint dataset were examined, out of which only 2405 were matched. Similarly, 28700 terms of Sarcasm dataset were tested out of which merely 4701 were matched. Subsequently, 82 terms of UoA dataset were examined on SRM, out of which 70 were matched. Lastly, the 60 terms for HUA were tested and out of which 50 were matched. The results show variations in matching of terms with the use of SRM, but it performed well on the UoA and HUA datasets.

On the other hand of analysis, the input datasets are used to test the performance of MRM. At first, 12820 terms of ACE2020 were tested on MRM, out of which 9125 were matched magnificently. Subsequently, 10960 terms of Aquaint dataset were examined, out of which only 7865 matched well. Similarly, 28700 terms of Sarcasm dataset were tested out of which 19998 were matched perfectly. Afterwards, 82 terms of UoA dataset were examined on SRM, out of which 50 were matched. Last of all, the 60 terms for HUA were tested and out of which 31 were matched.
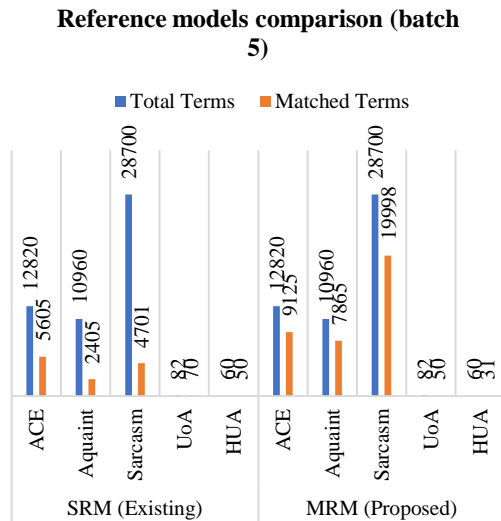
Fig. 6. Number of succesfully matched terms for MRM and SRM on batch 5.

For validation of performance, the SRM and MRM results are presented here. The comparison of performances (in terms of percentage) is depicted in Fig. 6.



| | ACE | Aquaint | Sarcasm | UoA | HUA |
|---|---|---|---|---|---|
| SRM | 43.72 | 21.94 | 16.38 | 85.37 | 83.33 |
| MRM | 71.18 | 71.76 | 69.68 | 60.98 | 51.67 |
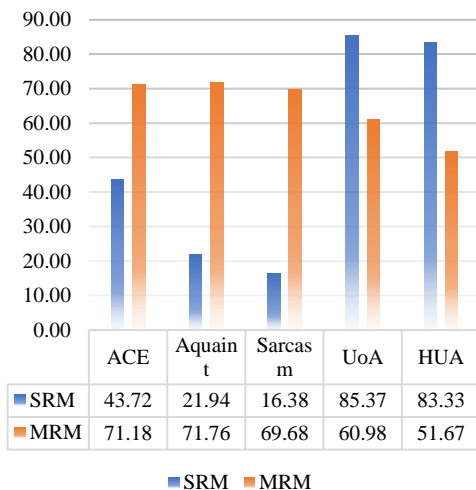
Fig. 7. Percentage of matched terms for MRM and SRM on batch 5.

The performance findings from this round suggest that the MRM performed better than SRM on ACE 2020, Aquaint and Sarcasm datasets whereas the SRM works better on HUA and UoA datasets.

Fig. 7 illustrates the terms matched (in terms of matched percentage) with both reference models on participating datasets. The percentage of matched terms using SRM for ACE2020, Aquaint, Sarcasm, UoA and HUA are 44%, 22%, 17%, 85% and 83%, respectively. Whereas percentage of matched terms using MRM for ACE2020, Aquaint, Sarcasm, UoA and HUA are 71%, 72%, 70%, 61% and 52%, respectively. This is because the proposed MRM covers multiple dimensions such as context, semantic and syntactic clues.

One of the significant contributions of MRM is that it checks each participating word/token from input dataset in domain knowledge by adopting the functionality of indexing. With that, the input tokens are checked multiple times and based on the context and similarity score of the index. It's worth noting that if any of the tokens' score is high based on the similarity but the score is less in terms of context then the terms which matched based on the context are selected. Whereas the existing SRM only checks the similarity based on string similarity and only in single dimension.

Comparative analysis on the results of SRM and MRM shows that the performance of MRM is better than the SRM on ACE 20202, Aquaint and Sarcasm datasets while the SRM performs better on HUA and UoA datasets. The results of MRM on UoA and HUA datasets are low which is due to different domain knowledge (medical) of the datasets.

## V. DISCUSSION

The multidimensional reference model has been developed for the domain knowledge. MRM helped in expanding the domain knowledge using the linguistics word categories such as lexical, semantic, and syntactic. In this research MRM was tested in multiple rounds (1-5 batches) on heterogeneous datasets from diverse domain. It enhanced the coverage of words and helped in term harmonization. The MR contains the 37321 words as a rich template in form of domain knowledge /data dictionary. List of words from lexical, semantic, and syntactic clues containing mrm-score() have been formed.

Evaluation of MRM on different datasets is performed using similarity score (in percentage). If similarity score is high, it means the more root words are matched with input words. From all the experiments it shows the proposed work is more scalable and it includes more similar words on basis on mrm_score(). With that, it has been observed that the matched terms for the ACE2020, Aquaint, Sarcasm have been covered more than that of UoA and HUA datasets. This is due to the fact that the ACE2020, Aquaint, Sarcasm covers daily life routine whereas the UoA and HUA contain data of medical domain.

## VI. CONCLUSION

During the literature review and aiming to find solutions to solve the data heterogeneity, it was found that the only possible solution to solve the problem is to harmonize data. By adopting many techniques such as semantic, lexical matching and reference matching template. Based on that, a reference model which was developed by [14] for data curation framework for medical cohort taken as baseline study. In that, the reference model (SRM) contains the domain knowledge of specific terms that were used in medical domain. The performance of MRM has been evaluated on five heterogeneous (structured, semi-structured and unstructured) datasets and in five multiple rounds. The results of each rounds of ACE20220, Aquaint, Sarcasm, UoA and HUA show better performance of MRM over its counterpart reference model i.e., Single dimensional reference model. The overall performance of MRM on all participating datasets is more than 30% on ACE2020, Aquaint, and Sarcasm datasets whereas the performance of UoA and HUA performed better on SRM. To

conclude with the performance of MRM, it has been observed that the use of MRM supports the DHF in selection of key terms based on semantic and lexical matched terms. Design and development of Multidimensional Reference Model which is developed based on the linguistics categories such as context, semantic and syntactic clues. The model enables the use of indexing for any English sentences by introducing the words and their respective score. The proposed MRM produced huge number of words that can be used as a reference for any general domain which contains daily basis data generated in textual formats.

## FUTURE RECOMMENDATIONS

Use of other categories of linguistics and computational linguistics for further improvement in the field of English grammar.

## ACKNOWLEDGMENT

## REFERENCES

[1] A. K. Bhadani and D. Jothimani, "Big data: Challenges, opportunities, and realities," Effective Big Data Management and Opportunities for Implementation, pp. 1–24, 2016, doi: 10.4018/978-1-5225-0182-4.ch001.

[2] H. Le Sueur, I. N. Bruce, N. Geifman, and N. Geifman, "The challenges in data integration - Heterogeneity and complexity in clinical trials and patient registries of Systemic Lupus Erythematosus," BMC Med Res Methodol, vol. 20, no. 1, pp. 1–5, 2020, doi: 10.1186/s12874-020-01057-0.

[3] N. Khan, M. Alsaqer, H. Shah, G. Badsha, A. A. Abbasi, and S. Salehian, "The 10 Vs, issues and challenges of big data," in ACM International Conference Proceeding Series, Association for Computing Machinery, Mar. 2018, pp. 52–56. doi: 10.1145/3206157.3206166.

[4] H. Jasim Hadi, A. Hameed Shnain, S. Hadishaheed, and A. Haji Ahmad, "Big Data and Five V'S Characteristics," International Journal of Advances in Electronics and Computer Science, no. 2, pp. 2393–2835, 2015.

[5] N. Khan, A. Naim, M. R. Hussain, Q. N. Naveed, N. Ahmad, and S. Qamar, "The 51 V's of big data: Survey, technologies, characteristics, opportunities, issues and challenges," ACM International Conference Proceeding Series, vol. Part F1481, pp. 19–24, 2019, doi: 10.1145/3312614.3312623.

[6] G. Kumar, S. Basri, A. A. Imam, and A. O. Balogun, Data Harmonization for Heterogeneous Datasets in Big Data - A Conceptual Model, vol. 1294. 2020. doi: 10.1007/978-3-030-63322-6_61.

[7] G. Kumar, S. Basri, A. A. Imam, S. A. Khowaja, L. F. Capretz, and A. O. Balogun, "Data harmonization for heterogeneous datasets: A systematic literature review," Applied Sciences (Switzerland), vol. 11, no. 17, 2021, doi: 10.3390/app11178275.

[8] M. A. Dootio and A. I. Wagan, "Development of Sindhi text corpus," Journal of King Saud University - Computer and Information Sciences, vol. 33, no. 4, pp. 468–475, 2021, doi: 10.1016/j.jksuci.2019.02.002.

[9] A. Wahl, S. T. Gries, and B. & Justus, "COMPUTATIONAL EXTRACTION OF FORMULAIC SEQUENCES FROM CORPORA: TWO CASE STUDIES OF A NEW EXTRACTION ALGORITHM."

[10] P. Aggarwal and R. Sharma, "Lexical and Syntactic cues to identify Reference Scope of Citance." [Online]. Available: http://wing.comp.nus.edu.sg/cl-scisumm2016/

[11] S. T. Gries and P. Durrant, "Analyzing co-occurrence data."

[12] J. Opitz, L. Parcalabescu, and A. Frank, "AMR Similarity Metrics from Principles", doi: 10.1162/tacl.

[13] V. C. Pezoulas et al., "Overcoming the barriers that obscure the interlinking and analysis of clinical data through harmonization and incremental learning," IEEE Open J Eng Med Biol, vol. 1, pp. 83–90, 2020, doi: 10.1109/OJEMB.2020.2981258.

[14] V. C. Pezoulas et al., "Medical data quality assessment: On the development of an automated framework for medical data curation," Comput Biol Med, vol. 107, no. December 2018, pp. 270–283, 2019, doi: 10.1016/j.compbiomed.2019.03.001.

[15] V. C. Pezoulas et al., "A hybrid data harmonization workflow using word embeddings for the interlinking of heterogeneous cross-domain clinical data structures," BHI 2021 - 2021 IEEE EMBS International Conference on Biomedical and Health Informatics, Proceedings, 2021, doi: 10.1109/BHI50953.2021.9508484.

[16] A. A. Imam et al., "Dsp: Schema design for non-relational applications," Symmetry (Basel), vol. 12, no. 11, pp. 1–33, 2020, doi: 10.3390/sym12111799.

[17] A. A. Imam, S. Basri, M. T. Gonzalez-Aparicio, A. O. Balogun, and G. Kumar, "NoInjection: Preventing Unsafe Queries on NoSQL-Document-model Databases," in Proceedings of 2022 2nd International Conference on Computing and Information Technology, ICCIT 2022, 2022. doi: 10.1109/ICCIT52419.2022.9711654.

[18] S. T. Gries, "Behavioral profiles: A corpus-based perspective on synonymy and antonymy *."

[19] M. Becker, K. Korfhage, and A. Frank, "COCO-EX: A Tool for Linking Concepts from Texts to ConceptNet." [Online].

[20] Balogun, A.O., Basri, S., Abdulkadir, S.J., Mahamad, S., Al-momamni, M.A., Imam, A.A. and Kumar, G.M., 2021. Rank aggregation based multi-filter feature selection method for software defect prediction. In Advances in Cyber Security: Second International Conference, ACeS 2020, Penang, Malaysia, December 8-9, 2020, Revised Selected Papers 2 (pp. 371-383). Springer Singapore.

[21] Balogun, A.O., Basri, S., Mahamad, S., Capretz, L.F., Imam, A.A., Almomani, M.A., Adeyemo, V.E. and Kumar, G., 2021. A novel rank aggregation-based hybrid multifilter wrapper feature selection method in software defect prediction. Computational intelligence and neuroscience, 2021.

APPENDIX A
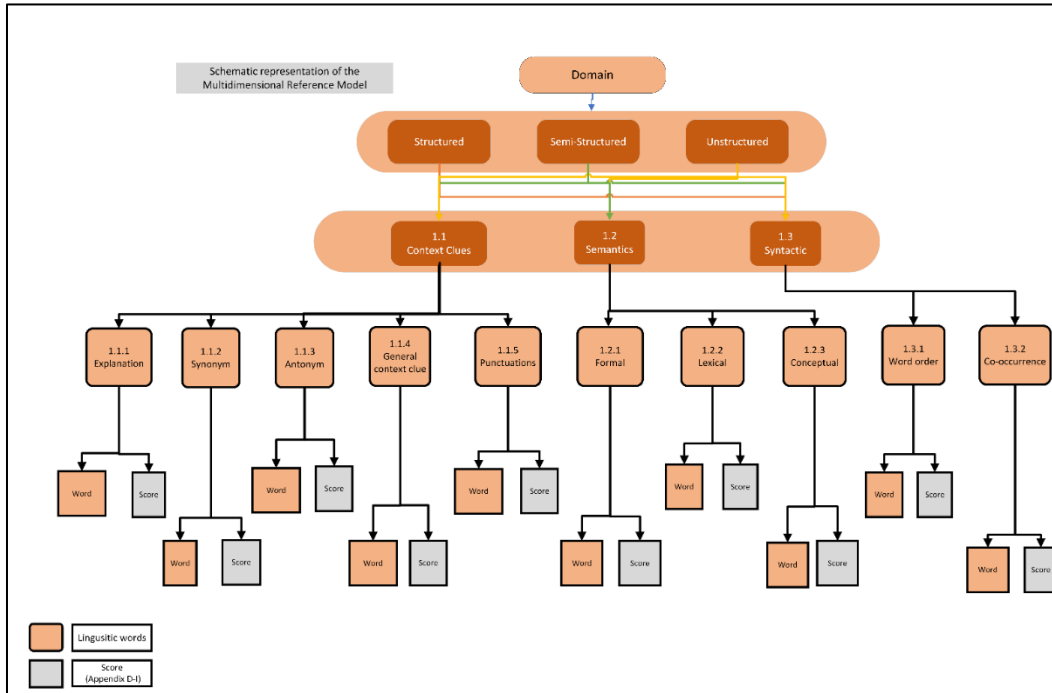


Fig. 8.    Percentage of matched terms for MRM and SRM on batch 5.

APPENDIX B

TABLE I.        TABLE TYPE STYLES

| Datasets | Reference Models Performances Batches | SRM | | | MRM | | |
|---|---|---|---|---|---|---|---|
| | | Total terms | Total Matched terms | Matched terms % | Total terms | Total Matched terms | Matched terms % |
| **ACE 2020** | Batch 1 | 2564 | 1212 | 47.27 | 2564 | 2080 | 81.12 |
| | Batch 5 | 12820 | 5605 | 43.72 | 12820 | 9125 | 71.18 |
| | **Average** | **7692** | **3457.60** | **45.57** | **7692** | **5689.4** | **75.64** |
| **Aquaint** | Batch 1 | 2192 | 551 | 25.14 | 2192 | 1678 | 76.55 |
| | Batch 5 | 10960 | 2405 | 21.94 | 10960 | 7865 | 71.76 |
| | **Average** | **6576** | **1511.20** | **23.57** | **6576** | **4797.4** | **73.68** |
| **Sarcasm** | Batch 1 | 5740 | 1198 | 20.87 | 5740 | 4568 | 79.58 |
| | Batch 5 | 28700 | 4701 | 16.38 | 28700 | 19998 | 69.68 |
| | **Average** | **17320** | **3108.40** | **18.69** | **17320** | **12686.8** | **75.01** |
| **UoA** | Batch 1 | 16 | 15 | 93.75 | 16 | 11 | 68.75 |
| | Batch 5 | 82 | 70 | 85.37 | 82 | 50 | 60.98 |
| | **Average** | **49** | **43.00** | **88.83** | **49** | **30.6** | **63.34** |
| **HUA** | Batch 1 | 12 | 11 | 91.67 | 12 | 7 | 58.33 |
| | Batch 5 | 60 | 50 | 83.33 | 60 | 31 | 51.67 |
| | **Average** | **36** | **31.40** | **88.61** | **36** | **19.2** | **54.22** |

APPENDIX C, D

| | | |
|---|---|---|
| smart | intelligent | 9.2 |
| hard | difficult | 8.77 |
| happy | cheerful | 9.55 |
| fast | rapid | 8.75 |
| happy | glad | 9.17 |
| stupid | dumb | 9.58 |
| weird | strange | 8.93 |
| insane | crazy | 9.57 |
| large | huge | 9.47 |
| quick | rapid | 9.7 |
| wonderful | terrific | 8.63 |
| strange | odd | 9.02 |
| simple | easy | 9.4 |
| inexpensive | cheap | 8.72 |
| weird | odd | 9.2 |
| large | big | 9.55 |
| essential | necessary | 8.97 |
| crucial | important | 8.82 |
| scarce | rare | 9.17 |
| bizarre | strange | 9.37 |
| delightful | wonderful | 8.65 |
| friend | buddy | 8.78 |
| student | pupil | 9.35 |
| teacher | instructor | 9.25 |
| movie | film | 8.87 |
| area | region | 9.47 |

**simlex999** ⊕

| | | |
|---|---|---|
| happy | mad | 0.95 |
| sharp | dull | 0.6 |
| old | fresh | 0.87 |
| weird | normal | 0.72 |
| sad | funny | 0.95 |
| nice | cruel | 0.67 |
| unnecessa | necessar | 0.63 |
| dumb | intelliger | 0.75 |
| bad | great | 0.35 |
| difficult | simple | 0.87 |
| bad | terrific | 0.65 |
| easy | tough | 0.52 |
| modern | ancient | 0.73 |
| new | ancient | 0.23 |
| dull | funny | 0.55 |
| tiny | huge | 0.6 |
| dumb | rare | 0.48 |
| sly | tough | 0.58 |
| terrific | mad | 0.4 |
| modest | flexible | 0.98 |
| fresh | wide | 0.4 |
| huge | dumb | 0.48 |
| large | flexible | 0.48 |
| dirty | narrow | 0.3 |
| bottom | top | 0.7 |
| absence | presence | 0.4 |
| reality | fantasy | 1.03 |
| bed | hospital | 0.92 |
| destruction | construc | 0.98 |
| brother | soul | 0.97 |
| car | bridge | 0.95 |
| denial | confessi | 1.03 |
| car | elevator | 1.03 |
| car | hose | 0.87 |
| chapter | choice | 0.48 |
| belief | flower | 0.4 |
| trick | size | 0.48 |
| choice | vein | 0.98 |
| hymn | conques | 0.68 |
| endurance | band | 0.4 |
| condition | boy | 0.48 |
| flower | enduran | 0.4 |
| hole | agreeme | 0.3 |
| doctor | temper | 0.48 |
| fraternity | door | 0.68 |
| task | woman | 0.68 |
| fraternity | baseball | 0.00 |

SAMPLES OF LINGUISTICS CONTEXT (SYNONYMS AND ANTONYMS)

APPENDIX E, F

| | | | |
|---|---|---|---|
| | Obama to name Susan Rice as national security adviser | Donilon out, Rice in as Obama's national security adviser | |
| 1.3 | The foundations of South Africa are built on Nelson Mandela's memory | Australian politicians lament over Nelson Mandela's death | |
| 3 | Turkish riot police tear gas Taksim Square protest | Turkish riot police enter Taksim Square | |
| 5 | Chicago Shooting Shows Gap in Stepped-up Policing | Chicago shooting shows gap in stepped-up policing | |
| 1.2 | Ukraine protest leaders name ministers, Russian troops on alert | Ukraine Refuses to Act Against Russian 'Provocation' | |
| 1.2 | North Korea shuns offer of talks | North Korea shoots 2 rockets | |
| 5 | Prince Charles 'compares Putin to Hitler' | Prince Charles 'compares Vladimir Putin to Adolf Hitler' | |
| 3.6 | Malala, Snowden, Belarusians Short-Listed For Sakharov Prize | Fugitive Snowden short-listed for European rights prize | |
| 1.2 | Israel PM accuses Iran president of hypocrisy | Greek PM accuses coalition of hypocrisy | |
| 3.2 | One dead in Philadelphia building collapse, others pulled from rubble | Six confirmed dead after Philadelphia building collapse | Samples of Lexical Semantics (Formal) |
| 2.8 | Police clash with youth in Cairo after anti-Morsi protest | Egypt: Police clash with pro-Morsi protesters | |
| 2.4 | Top Diplomats Meet in Munich at Critical Time | Top Diplomats Discuss Iran's Nuclear Program | |
| 1.2 | Snowden 'given refugee document by Ecuador' | Snowden poised to fly out of Moscow | |
| 2.2 | NA President‚Äôs message on the World Press Freedom Day | Pakistan marks World Press Freedom Day | |
| 3.6 | EU foreign ministers to discuss Syria arms embargo | EU foreign ministers seek solution on Syria arms | |
| 3.6 | Death toll from Philippine earthquake rises to 185 | Death toll from Philippines quake rises to 144 | |
| 4 | Stocks to watch at close on Monday | Stocks to watch on Monday | |
| 3.2 | Army jets kill 38 militants in NW Pakistan air raids | U.S. drone kills 4 militants in Pakistan | |
| 4 | Egyptian police fire tear gas at protesters in Cairo | Police fire tear gas at protesters in Cairo | |
| 3.2 | ElBaradei to Become Egyptian PM | Liberal ElBaradei named Egypt PM, Islamists cry foul | |
| 1.4 | Philippines holds second senator over corruption | Philippines recovering after powerful typhoon | |
| 1.4 | German envoy optimistic about Iran-G5+1 talks | Iran 'cautiously optimistic' about future nuclear talks | |
| 4.6 | Renowned Spanish flamenco guitarist Paco De Lucia dies | Spanish flamenco guitarist Paco de Lucia dies at 66 | |
| 2 | Chinese icebreaker changes course towards suspicious objects | Chinese search plane finds 'suspicious objects' | |
| 5 | Snowden Hits Hurdles in Search for Asylum | Snowden's hits hurdles in search for asylum | |
| 2.8 | Death toll in building collapse in south India mounts to 47 | 4 killed in building collapse in southern India | |
| 1.4 | Pakistan imposes temporary ban on 2 TV channels | Pakistan Dismisses Case against FBI Agent | |
| 1 | Palestinian prisoners arrive at Muqata in Ramallah | Pakistani prisoner assaulted in Jammu jail | |
| 1 | 10 dead, five injured in SW China road accident | 5 hurt in Gaza City car accident | |
| 5 | Matt Smith quits BBC‚Äôs Doctor Who | Matt Smith quits BBC's Doctor Who | |
| 1.8 | Thai junta amasses security force to smother Bangkok protests | Thai junta security forces stay in barracks as protests dwindle | |
| 1 | Queen pays tribute to Nelson Mandela | South Africa's rugby fraternity mourns Mandela | |
| 0.4 | Declines in US stock market moderate | Tech sell-off sends Asian stock markets lower | |
| 2.6 | Latest Anti-Muslim Violence in Burma Kills 1, Injures 10 | World Briefing \| Asia: Myanmar: Deadly Anti-Muslim Violence Flares Up | |
| 3.8 | Suspected U.S. drone strike kills 5 in Pakistan | U.S. drone strike kills 5 in Pakistan | |
| 2 | The Note's Must-Reads for Friday May 24, 2013 | The Note's Must-Reads for Tuesday October 29, 2013 | |
| 0.6 | 22 killed in mine accident in southwestern China | 2 killed, dozens injured by blast in southwest Pakistan | |
| 4.8 | NYPD Twitter Outreach Backfires Badly | NYPD's twitter campaign backfires | |
| 4.4 | 19 hurt in New Orleans shooting | Police: 19 hurt in NOLA Mother's Day shooting | |
| 3.8 | Another migrant ship capsizes off Italy | Another migrant boat capsizes off Italy, 27 dead | |
| 5 | Turkish search ends as last missing miners found | Turkish Search Ends as Last Missing Miners Found | |
| 1.4 | Iran predicts failure of Israeli-Palestinian peace talks | Tentative Deal Reached to Resume Israeli-Palestinian Talks - US | |
| 4.4 | Olivia Colman wins second BAFTA Award | Baftas 2013: Olivia Colman picks up two awards | |
| 3.8 | Titanic Violin Nabs Record $1.4 Million | Titanic violin sells for $1.7 million | Samples of Lexical Semantics (Lexical) |
| 5 | Ankeet Chavan granted conditional bail for marriage | Ankeet Chavan granted bail to get married | |
| 3 | JAL's first order from Airbus is blow to Boeing | Japan Airlines orders 31 Airbus A350s valued at $9.5 bn | |
| 3 | Sienna Miller testifies at UK phone hacking trial | Sienna Miller attacks press for ‚Äëtitillating‚Äô reports at hacking trial | |
| 2.6 | Israelis attack 2 Palestinians in Jerusalem area | Settlers Beat up Palestinian in Jerusalem | |
| 0.4 | EU extends sanctions against Russia | Nigeria drops arms trafficking charges against Russian sailors | |
| 3.4 | ‚ÄëGlee‚Äô star Cory Monteith found dead in hotel room | Cory Monteith found dead: Canadian ‚ÄëGlee‚Äô star was 31 | |
| 4.6 | Lebanon's PM forms 'unity cabinet' Lebanon's prime minister has formed a cabinet more than 10 months after taking office, taking in a wide range of political groups after bridging serious divisions am | BEIRUT: Lebanon's prime minister formed a cabinet more than 10 months after taking office yesterday, including a wide range of political groups after bridging serious divisions among them mostly over | |
| 0.6 | Iranian president makes debut on world stage | broken | |
| 1.2 | Scores Killed In Egyptian Protests | Turkey's PM Warns Against Protests | |
| 3.8 | State Dept. issues wide travel alert, says terror attack possible | US issues global travel alert, cites al-Qaida threat | |
| 4.6 | Michelle Obama To Star In Parks And Recreation | Michelle Obama to appear on 'Parks and Recreation' | |
| 1.6 | Singapore stocks end up 0.11 pct | Singapore stocks end down 0.45% | |
| 4.6 | World's oldest man dies at 116 | World's oldest ever man dies aged 116 | |
| 2.8 | Death toll in Lebanon bombings rises to 47 | 1 suspect arrested after Lebanon car bombings kill 45 | |
| 5 | Greek far-right leader imprisoned pending trial | Greek Far-Right Leader Imprisoned Pending Trial | |

APPENDIX G

| you know | INT | 27348 | The big step is then getting the rest of the Council to take it on board, that's the big step, ···the development budget there went on projects for young people, you know, so there |
|---|---|---|---|
| I think (that) | CA | 25862 | I think I've still got the piece about that. |
| a bit | NP | 7766 | Can you move round this side a bit? |
| (always [155], never [87]) used to {INF} | VP | 7663 | We used to look forward to them coming. |
| as well | AVP | 5754 | Can I just say something else as well? |
| a lot of {N} | NP | 5750 | I got a lot of letters from the children there and which was very gratifying. |
| {No.}pounds | NP | 5598 | I'd also ask you to consider costs of ten pounds. |
| thank you | VP | 4789 | Well thank you for that that's a very good start to the evening. |
| {No.}years | NP | 4237 | I've done it for seven years. |
| in fact | PP | 3009 | In fact, if the previous speaker has complained about waiting in patience, I have waited forty years to tell this story in the assembly··· |
| very much | AVP | 2818 | ···they enjoy it very much··· |
| {No.}pound | NP | 2719 | I've got to take a taxi of one pound forty a day to shop... |
| talking about {sth} | VP | 2489 | It was a different from what you're talking about. |
| (about [91]) {No.} percent (of sth [580], in sth [ | NP | 2312 | As I said, we've already got forty one percent of themain funding required for the project... |
| I suppose (that) | VP | 2281 | I suppose that was one way of nothing being done. |
| at the moment | PP | 2176 | Well I haven't done anything at the moment because I didn't think it was worth it actually. |
| a little bit | NP | 1935 | And the other times your concentration will drop a little bit. |
| looking at {sth} | VP | 1849 | I think there's another way of looking at that. |
| this morning | AVP/NP | 1846 | Oh she was screaming this morning. |
| (not) any more | AP | 1793 | ···women shouldn't have off days any more. |
| come on | INT | 1778 | No, it's not a verb, come on, what is it? |
| number{No.} | NP | 1661 | Number six which is the thing that we have to look at. |
| come in (swe, sth) | VP | 1571 | We're about to finish, so please come in. |
| come back | VP | 1547 | We'll come back to you in a second. |
| have a look | VP | 1471 | You can go and have a look. |
| in terms of {sth} | PP | 1463 | I think it was one of the things which never really took off in terms of the accident. |
| last year | AVP/NP | 1347 | That was last year or was that two years ago? |
| so much | AP/AVP | 1334 | He loved the sea so much. |
| {No.}years ago | AVP | 1314 | That was last year or was that two years ago? |

SAMPLES OF WORD-ORDER

APPENDIX H

| 1. well | as well | AVP | 5754 | Can I just say something else as well? |
|---|---|---|---|---|
| | very well | AP/AVP | 987 | You can read very well can't you? |
| | as well as | C/P | 620 | ···other schools in the area used to use this facility as well as we did. |
| | well done | VP | 171 | Top of the class, well done. |
| | really well | AVP | 118 | I've done really well. |
| | quite well | AP | 94 | I thought it was quite well organized considering. |
| | so well | AP | 80 | ···got the final ball wrong but a shame he'd done so well. |
| | well known | VP | 74 | I mean it's more well known than it used to be. |
| | very well | INT | 68 | Very well, thanks |
| | here as well | AVP | 47 | Feels warm in here as well. |
| | pretty well | AVP | 43 | Dave's got a job pretty well hasn't he? |
| | very well | AP | 12 | he's not very well, he looks how pale he is, James is quite pale as well |
| | | | | |
| 2. know | you know | INT | 27348 | The big step is then getting the rest of the Council to take it on board, that's the big step, ···the development budget there went on projects for young pec |
| | know that (S V) | VP | 889 | ···you know that this is the only room available. |
| | know it | VP | 469 | It doesn't really worry me whether you know it or not. |
| | know if {S V} | VP | 321 | I don't know if any of you are old enough to remember··· |
| | know whether {S V} | VP | 247 | I don't know whether anybody would disagree with that. |
| | as I know | CA | 95 | ...just as I know I must call my lady Anne! |
| | know this | VP | 88 | ···issue of drawings to the client wished to know, wished to know this. |
| | (not) know anything | VP | 66 | ···I don't really know anything special about me. |
| | know the one | VP | 56 | Ruth, you know the one I used to look after? |
| | know the answer | VP | 47 | Well I supposed we'd all like to know the answer to that. |
| | know one | VP | 42 | I know one who wouldn't stand for it. |

SAMPLES OF CO-OCCURRENCE WORDS

# Application of Lightweight Deep Learning Model in Landscape Architecture Planning and Design

Linyu Zhang

Department of Arts
AnYang University
Anyang 455000, China

*Abstract*—The holistic view of garden construction is firstly reflected in the integration of the elements that make up the garden, and the primary and secondary are distinguished from the perspective of the whole city, the continuation of the upper planning, the coordination with the surrounding groups and the harmony of the internal gardening elements. The primary goal of ANN (artificial neural network) learning is to understand the drawings and to convert information such as plant numbers and positions in digital drawings into standard digital formats for storage. In front of the SSD (Single Shot Multi-box Dettor) network model, a standard architecture network for image classification is adopted, called the basic network and is fused for comprehensive detection. This paper proposes the network model flow of the 3D object voxel modeling method based on the lightweight DL (Deep learning) model. The cyclic 2D encoder, cyclic 3D decoder and view planner are integrated into a unified framework responsible for feature extraction and fusion, feature decoding and view planning. The results show that the pixel accuracy, the average accuracy and the average IU value are the highest, with the pixel accuracy as high as 90.44%, the average accuracy as high as 93.15%, and the average IU value as 92.72%. In landscape image processing, it provides a certain foundation for future landscape planning and design.

*Keywords—Deep learning; landscape architecture; landscape element; neural network; artificial neural network; view planning*

## I. INTRODUCTION

Traditional landscape architecture planning and design methods mainly rely on designers' accumulated and improved experience. For large-scale landscape planning applications, designers must have solid design theory, professional design skills and extensive artistic accomplishment [1]. Scale and pattern process is called two core issues of landscape ecology [2], and scale effect is the core of three major issues in scale grade research: scale effect, scale selection and scale deduction. In today's era of globalization, although economy, culture and customs learn from each other in mutual communication, the different civilisations hidden behind them cannot be converged. The discipline of landscape architecture is developing daily, and the industry is in a rapid development stage, bringing unprecedented opportunities and prosperity to landscape architects. With the development of the social economy and the improvement of people's spiritual level, more attention has been paid to environmental quality. Modern landscape architecture is a "scientific art", which cannot be separated from art, but also from the support of science. Therefore, the discipline of landscape architecture needs to

form its own methodology and theoretical system and become a rigorous and mature discipline.

Landscape planning and design is a highly comprehensive design art that involves the planning and layout of multiple elements such as terrain, plants, water bodies, buildings, etc. In traditional garden planning and design, designers usually rely on experience and personal aesthetics to design. However, this approach often lacks precise data support and scientific decision-making basis, which can easily lead to low design efficiency or not meeting practical needs. The emergence of deep learning models provides new solutions for landscape planning and design. Through deep learning technology which can learn and analyze a large amount of historical garden design data, in order to uncover the laws and features hidden behind the design. These laws and characteristics can be used to optimize the design process, improve design efficiency, and enhance the scientificity and feasibility of design schemes. The application scenarios of deep learning models in landscape planning and design are very extensive. For example, digital terrain simulation is an important part of landscape planning and design, involving multiple steps such as terrain measurement, analysis, and modeling. By utilizing deep learning technology, it can quickly and accurately identify and analyze terrain data, providing designers with reliable terrain data support.

At present, with the development of China's landscape architecture industry, many excellent landscape architecture planning and design concepts have emerged, and they are committed to creating modern landscape architecture with Chinese characteristics based on local conditions—research on shape and space generation is controlled by focusing parameters. Systematic parametric design research has not been carried out according to the characteristics of landscape architecture planning and design; not only the practice of parametric landscape architecture design is rare, but also the research on the theory and method of parametric design of landscape architecture itself is even less. Aiming at the current industry situation, this paper mainly explores the application of the lightweight DL model in landscape architecture planning and design. It summarizes its reference and guiding significance for modern landscape architecture planning and layout to enrich and develop the theory and practice of modern landscape architecture planning and design in China to guide the future landscape architecture planning and design practice. Scientific intervention, adjustment, planning and design of landscape environment through parametric method are an

important development direction and research difficulty of modern landscape architecture planning and design. This article proposes a network modeling process for a three-dimensional voxel modeling method. Integrating the graphic planning of the encoder, the pixel accuracy is improved during the feature extraction process. The innovative points of the method adopted in this article are:

*1)* Lightweight DL models have lower model complexity and computational complexity, enabling fast training and inference under limited computing resources and memory constraints, making 3D object voxel modeling more efficient and real-time.

*2)* Lightweight DL models can improve the accuracy and detail representation ability of 3D object voxel modeling through network structure and algorithm optimization, thereby better reflecting actual 3D scenes and objects.

*3)* Lightweight DL models have a small model volume and parameter quantity, which can be deployed and run on various devices, facilitating model updates and upgrades, thereby supporting the diversity and scalability of 3D object voxel modeling.

## II. Literature Review

Since the 1950s, the destruction of the natural environment caused by industrialization has become increasingly serious, and people have begun to attach importance to the role of natural ecological elements in planning. Various ecological planning schools, led by landscape suitability evaluation methods, have successfully proposed a series of planning strategies to coordinate natural and human elements [3], [4]. Thorne et al. put forward the suitability evaluation method, the core of which is to synthesize and screen all kinds of environmental factors and socio-economic factors in time order to solve practical planning problems [5]. Economic elements are integrated and screened to solve practical planning problems, so it is also called "a thousand-layer cake" figuratively. Parris et al. store all kinds of landscape elements on the map in the form of raster data or vector data and give them specific structures and attributes. This change in the storage mode of map information makes the amount of information in a map much larger than the traditional map [6]. Ankita et al. used Arcview GIS and visualization software to create three-dimensional effects for environmental assessment. If landscape architects can accept such a technology, it will be fundamentally incorporated into the design process and can positively influence the social impact of design [7]. Shuvo et al. segmented the image by the color of the flowers, extracted the features based on texture analysis, and finally combined it with SVM (support vector machine) and other methods to realize the classification and recognition of flowers [8]. DL (Deep learning) is very important in computer vision. With the continuous progress of its technology, its application in the classification and recognition of flower images has greatly improved the effect of classification and recognition [9]. Wei et al. adopted the CNN model of the Keras DL framework and trained the Oxford flower data set to greatly improve the accuracy of flower species identification [10]. Qiang et al. combined the self-coding network structure with the

classification network and, through the post-processing of graphic synthesis technology, input a single-view picture and output the predicted and synthesized three-dimensional model [11]; Li et al. put forward a three-dimensional RNN (Recurrent Neural Network). By building a three-dimensional RNN, pictures taken from multiple perspectives are received, and the network's hidden layer is used to implicitly represent the geometric structure of the current reconstruction, thus establishing a DL three-dimensional reconstruction framework combining single and multiple perspectives [12]. Wang et al. obtained better simulation results than multi-dimensional time series by adopting the fluctuating time series simulation method. Fluctuating time series is a method of making the series conform to Fourier series by using difference, and usually monotonous data can be changed into fluctuating type by contrast [13].

## III. Research Method

### A. General Principles of Landscape Design

The holistic view of garden construction is firstly reflected in the integration of the elements that make up the garden, and the primary and secondary are distinguished from the perspective of the whole city, the continuation of the upper planning, the coordination with the surrounding groups and the harmony of the internal gardening elements. By protecting the natural and cultural landscapes in the site, it can pay attention to the spirit of the site, respect each specific area and strive to create its complementary design and interpret the traditional spirit with modern techniques to achieve the unity of natural harmony with the site itself [14], [15]. Planning and symbolically creating different landscape forms (people and designers transfer their landscape views to space, city and landscape), bringing about spiritual changes.

The technical evolution of the superposition method expands its operation mode and technical purpose. In other words, today's overlay method is no longer limited to a specific technical means or operation process but a set of tools oriented by cascading thinking, which includes a series of techniques. General maps tend to show as much information as possible in one map, while thematic maps focus on expressing one or several elements. This feature of the thematic map makes the main information to be expressed emphasized, while the secondary data is weakened as much as possible.

The thematic map is no longer limited to the traditional division of physical and geographical elements but is replaced by the distribution of various diseases in the study area, and the degree of incidence is expressed by color depth. It should be noted that the superposition between thematic maps of factors or elements is not necessarily the superposition of all drawings. Still, the superposition is carried out selectively according to the research needs. From this, it can summarize the general operation steps of the overlay method as shown in Fig. 1:

The main difference between the application of the superposition method in the above three cases lies in the theoretical basis followed by users and the final results of the superposition method. The theoretical basis determines the classification of landscape elements and the splitting method of their corresponding factors. At the same time, the final result of

overlapping images depends on the goal orientation of landscape architecture planning and design itself. Therefore, the final superposition should draw thematic maps of various diseases, population density maps and environmental maps of health and diseases and also superimpose these maps again to explore the relationship between the elements.
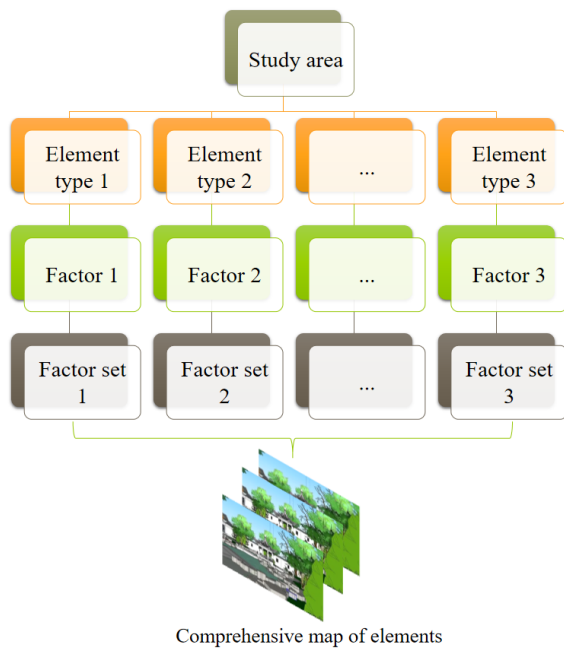


Fig. 1. General operation steps of the superposition method.

According to the connotation of the mechanism, it need to grasp it from two aspects: First, the system, that is, something is a system composed of multiple parts, and each piece is related, which is also the premise of the existence of the mechanism; The second is the operation mode, that is, the specific action mode of the mechanism to coordinate the relationship between various parts of things. Design mechanism, like the "invisible hand" directing the design, guides design behavior and generates design results. As the same research on scientific design methods, compared with design patterns, design mechanism pays more attention to the explanation of action mechanism, the grasp of laws and the exploration of design essence, which is more flexible and instructive. In addition, the design mechanism can be transformed into corresponding design patterns according to different juice designs, which is more suitable and practical.

The core of ancient Chinese culture is local culture, and the countryside is a world close to nature and with disputes over rights, which have always been yearned for by scholars. The essence it pursues is a kind of life close to nature. In the eyes of Western scholars, geography is to explain "the relationship between man and earth". The interaction between human beings and landscape, social and personnel variation will also cause natural changes. Although mixed with some metaphysical colors, its essence reflects the theory of base selection and site planning and design of residential environments such as houses, villages and towns in China. People plan for experience. First of all, it is a clear purpose or experience, and secondly, it is a conscious design with the form and space quality to achieve the project's space effect or create according to the goal set by the task book. Only through the best experience and expressing functions can the most optimized planning experience be produced.

### B. Plant Configuration in Landscape Planning and Design

The analysis and prediction of regional socio-economic status and development trend of planning is the starting point and important basis for planning. In the early stage of planning, it should focus on analyzing the current situation of social and economic structure in the planning area and its dynamic change law, and analyze the impact of social and economic system environment on land use to provide a real and reliable social and economic background for the formulation and implementation of the planning scheme. Through comprehensive balance and full coordination, the planning scheme can reasonably determine the scale and spatial layout of agricultural land, construction land, ecological protection areas, land development and consolidation, and key construction projects. It can reasonably determine the main control indicators such as cultivated land quantity, cultivated land occupied by construction, basic farmland protection area, land development and consolidation area, and the scale of construction land in major cities and towns.

People's cognitive activities begin with feelings. It reflects the objective things, the sensory perceiver touches through the sensory organs. It takes the objective things as the source, the subjective interpretation as the way and result, and the subjective image of the objective things in the mind. People's environmental identification aims to gain a foothold of complete mastery of thinking. If the system needs clarification, a familiar and comfortable environment with a clear and clear orientation system will give people affinity. In contrast, an unfamiliar, monotonous environment with an unclear orientation system will make people feel lost.

The spatial scale effect is a phenomenon that ecological objects show different characteristics and meanings with the change of spatial scale. The spatial dimension of scale can be changed by granularity and amplitude [16]. Time granularity refers to the frequency of object occurrence or the time interval of its dynamic change; Time range refers to the duration of an object in time. The time scale effect is a phenomenon in which ecological objects show different characteristics and meanings with the time scale change. When studying other objects, it should choose the appropriate time scale. Generally speaking, the high level of a nested system is composed of low levels, and the relationship between two adjacent levels is completely contained and completely contained [17], [18].

Taking plant configuration as an example, the primary goal of ANN (artificial neural network) learning is to understand the drawings. This understanding is not to identify what plants are in the drawings like people in the conventional sense or why they are matched like this, but to convert information such as plant numbers and positions in digital drawings into standard digital formats for storage. Many factors will influence the design process of plant configuration, and there are a lot of uncertain nonlinear conditions in the process, so there is a diversity of design results towards the target under specific conditions, similar to the non-convexity of ANN.

The neuron is the basic component and processing unit of the neural network. The structure of the artificial neuron model mainly includes the following three elements: group input and the intensity of input signal is expressed by the weight of each input neuron. The summing unit is used for weighting and summing all input signals. The activation function limits the output value of neurons in a certain range [19].

The $\theta_k$ threshold (or offset $b_k = \theta_k$ ) is expressed mathematically as follows:

$$v_k = \sum_{j=1}^{p} w_{kj} x_j \quad (1)$$

$$\mu_k = v_k + \theta_k \quad (2)$$

$$y_k = \phi(\mu_k) \quad (3)$$

$x_1, x_2, \cdots, w_{k1}, w_{k2}, \cdots, w_{kp}$ is the weight of the neuron, the activation function is $\phi(\cdot)$, and is the output of the $k$th neuron.

BP is the most commonly used ANN model in time series prediction, which is essentially a static network model. The input samples are random, and there is no correlation trend. From a mathematical point of view, the neural network is a nonlinear function. A time series $\{X_n\}$, which can be predicted by the following formula:

$$X_{n+k} = f(X_n, X_{n-1}, \cdots, X_1) \quad (4)$$

The static network is used to fit the function $f$, and then the future value is predicted. This is the basic idea of a neural network for time series prediction.

When the actual design work is carried out, it is necessary to consider the functional requirements put forward by the owner or the government, which requires the system to have certain control and guidance on the design results. Therefore, when constructing the network model, it is necessary to set the result-oriented control ability and the bottom-up generation logic. At the same time, it can adjust the threshold and incentive function of input data and influencing parameters. Fig. 2 shows the model structure of the self-generated system.

Assuming that the garden environment is $W$, the boundary is, and all polygon obstacle areas in the area are $Q_i$, then:

$$W = \{WSB, Q_1, Q_2, \cdots, Q_m\} \quad (5)$$

Where is the number of polygon obstacle areas?

SVD (Singular value decomposition) is an algorithm that can be applied to any matrix decomposition. For example, assuming that the input data of the full connection layer is $u \times v$ in size and the weight matrix is $W$, the calculation formula of the output data of the full connection layer is:

$$y = Wx \quad (6)$$

Its computational complexity is $u, v$. It $W$ is subjected to SVD and $W$ is approximately replaced by the first important eigenvalues after decomposition; the decomposition formula is:

$$W = U \sum V^T \approx U \sum_t V^T \quad (7)$$

$U$ represents an orthogonal matrix of dimension. Represents a diagonal matrix corresponding to the first values in the original diagonal matrix with dimension $t \times t$. It represents an orthogonal matrix of dimension.

Neural networks and traditional regression analysis are similar; both try to find the best fit for the function by minimizing the model's error. The fitting error of its model is given by Formula (8):

$$E = Y - f(X) \quad (8)$$

Because the value of the deviation term is always 1, its weight has the same function as the constant term in the regression model. Similarly, the network with HL (hidden layer) is similar to the nonlinear regression model, and for one HL, it is given by the following formula:

$$y = G\left(\sum_{j=1}^{k} \beta_j G\left(\sum_{i=1}^{m} \gamma_{ji} x_i\right)\right) \equiv f(x, \phi) \quad (9)$$
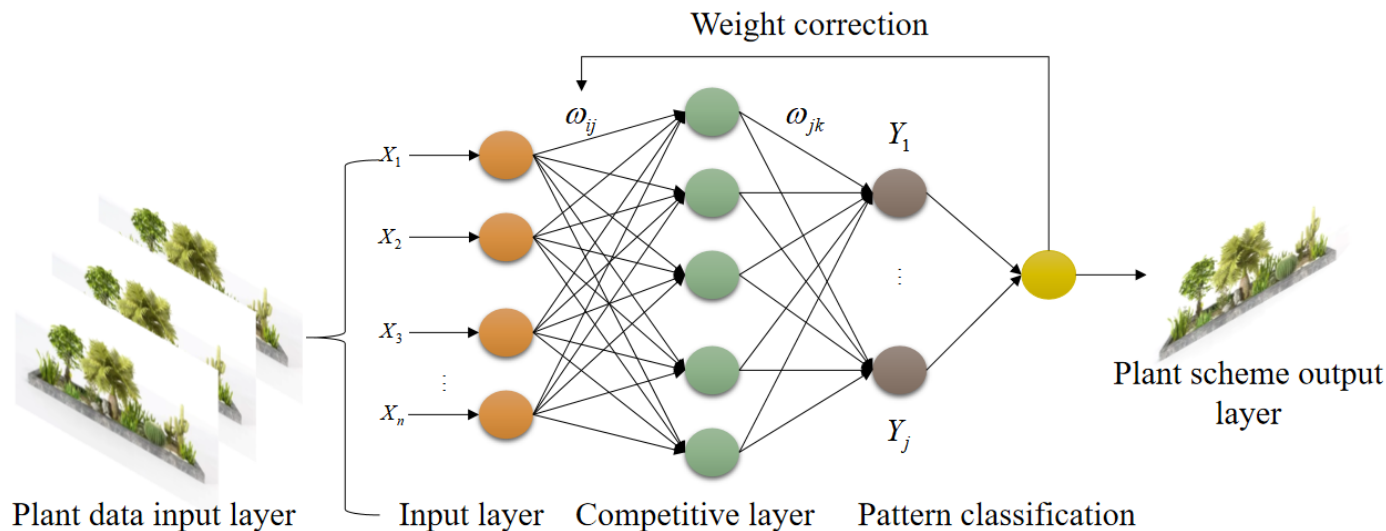


Fig. 2. Self-generated system model structure.

$G$ is the transformation function of HL and output layer in the neural network; $h$ is the number of HL neurons; $m$ is the number of input units; $\beta_j$ is the weight between output neurons and HL neurons, and is the weight between HL neurons and input neurons; $\varphi$ is all the relevant weights in the network, $x_i$ is the input value, and is the output value.

## C. Voxel Modeling Method of a Three-Dimensional Object based on Lightweight DL Model

In the emergence and development of regional humanistic features, the region's natural features play a great role. In the final analysis, no regional culture can exist and develop independently of its dependent environment, no matter how free human beings are in their choice of culture. Historical background, it can deeply study the development context of the region and understand the origin and changes of regional human characteristics. When designing, only by putting the thinking of the land parcel in an overall and macroscopic background of time and space and fully investigating and understanding the historical background of the region can it have a clear and comprehensive understanding of the emergence and development of the humanistic characteristics of the region, and then it can have a targeted and well-founded theory in the middle and later stages of design.

Western gardens are also more influenced by the agricultural rural landscape. No matter the grand royal gardens or the quiet private courtyards, you can see the shadow of the rural landscape at that time. This is completely different from the oriental garden, which has always been greatly influenced by the natural landscape and is good at imitating the natural mountain water potential in the garden construction.

Landscape planning and design is a discipline that integrates space art and time art, and landscape works, as an aesthetic entity, exist in space and time at the same time. Compared with architectural language, the biggest feature of garden design language is that it changes dynamically with time. Landscape elements such as vegetation and water in gardens will change dynamically with the seasons. Find a stable and lasting structure in the present situation of the base, and then plan a whole system based on various parameters, which must evolve with time and produce special coping methods with evolutionary ability.

Positioning and mapping are the position of the image observation point and the corresponding relationship between the observation point and the reconstructed model. In the shooting scene without camera position calibration, it is necessary to position the camera in the shooting process to judge the conversion relationship between the pixels and the 3D model and finally build the 3D map in the global coordinate system. You can use the characteristic point method or the direct method to complete a visual odometer. Taking the feature point method as an example, firstly, the features of the image are extracted, and the features between adjacent frames are matched. Then, based on the matched elements, the epipolar geometry method or nearest point iteration method is used to solve the pose change of the camera.

According to the transformation formula between homogeneous coordinates and pixel coordinates in the world coordinate system, the two-dimensional feature points are transformed into signposts on the three-dimensional map. The transformation relationship is as shown in Formula (10):

$$P_{uv} = KTP_w \qquad (10)$$

Among them are the camera's internal reference matrix, which is fixed after the camera leaves the factory, and its external reference matrix, which represents the camera's rotation and translation and changes with the camera's position.

Landscape images are developing vigorously. Although many drawings, drawings and landscape models are used now, the content brought by different image media is completely different. Now, the task of landscape architects is to keep learning and find suitable image media so that their works can be better displayed and expressed.

When semantically segmenting different landscape pictures, because it is impossible to correctly segment every object, sometimes the landscape element category in a certain image is regarded as another category [20]. In this paper, the model based on CNN (Convective Neural Network) can achieve the goal of semantic segmentation of landscape pixels in complex landscape images. The final output digital result is regarded as the final result of landscape element classification in the final landscape image to judge the final result of landscape element classification in the landscape image. Deep learning reinforcement learning (RL) algorithms can be used to optimize the design process, such as finding the best building materials, design elements, or layouts [21]. This can be achieved by training neural networks to learn and improve based on project requirements and constraints (such as budgets, regulations, etc.). Deep learning can be used to automatically generate 3D models of buildings. These models can not only be used for visualization, but also for structural analysis and optimization [22]. Deep learning can be used to achieve parameterized design, which means that every decision in the design process can be fine-tuned as a variable. For example, the design scheme can be optimized based on factors such as sunlight conditions, wind direction, terrain, etc. [23].

This paper represents the number of pixels that belong to class semantics and are judged to be class and is used to describe the total number of semantic categories. The formula used to calculate the average accuracy is shown in Formula (11):

$$A_{avg} = \frac{1}{n_{cl}} \sum_i \frac{n_{ij}}{t_i} \quad (11)$$

According to the theoretical discussion of 3D image reconstruction methods, it can be concluded that the DL method can make up for the limitations of traditional methods in view angle number, illumination, reflection, etc., to some extent and use less information to complete more efficient reconstruction.

In front of the SSD (Single Shot Multi-box Dettor) network model, a standard architecture network for image classification is adopted, called the basic network and is fused for comprehensive detection. Fig. 3 shows the network model flow chart of the 3D object voxel modeling method based on the lightweight DL model.
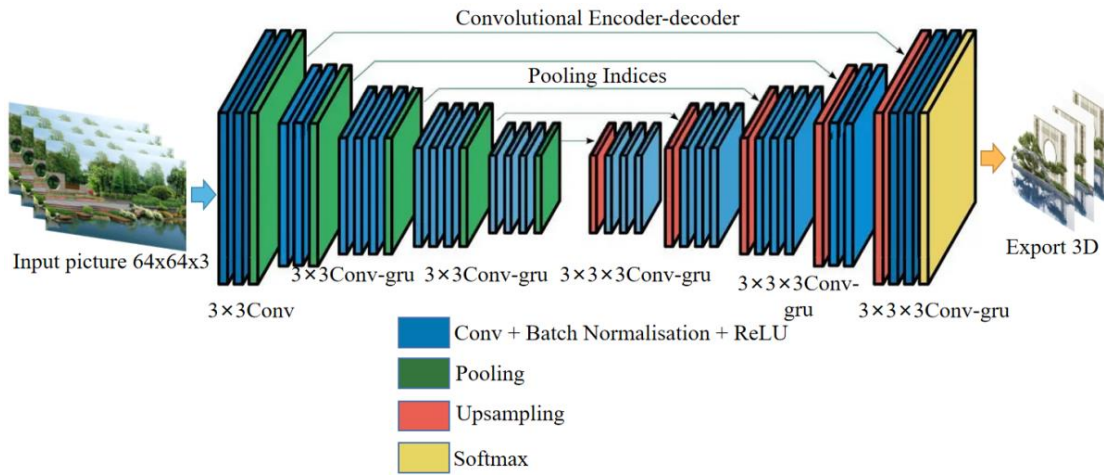
Fig. 3.   Network model flow chart of voxel modeling method of a three-dimensional object based on lightweight DL model.

In the network, the cyclic 2D encoder, cyclic 3D decoder and view planner are integrated into a unified framework, which is responsible for feature extraction and fusion, feature decoding and view planning, respectively, so that the system can dynamically plan the view independently and update the reconstructed model in a time step sequence.

In terms of network depth, because the size of the original image is large, redundancy may occur, so the feature changes of the original texture details can be captured by large convolution. When the original image is input, multiple convolution kernels repeatedly act at different positions to extract features in the convolution layer.

If convolution kernels convolve the input image, a $n$ feature map is obtained, and the operation formula is shown in Formula (12):

$$X_n^m = f\left(\sum_{i \in P_x} x_i^{m-1} * k_{in}^m + b_n^m\right) \quad (12)$$

The above formula represents the $n$ th characteristic graph of the convolution layer in the $m$ -th layer, $f$ is the activation function of this layer, $P_n$ represents the set of input images, and $b$ is the corresponding offset.

Because the batch gradient descent method needs to traverse all samples to update parameters, the experimental process is slow, so SGD (Stochastic Gradient Descent) is adopted in this experiment. Use the loss function of each sample to derive the partial derivative of the weight $w$:

$$w_j^i = w_j + \left(y_i - h_\theta(x_i)\right)x_j^t \quad (13)$$

Where $h(x)$ is the function to be fitted, $j(w)$ is the loss function, $\theta$ is the number record, and $j$ is the number of parameters?

$W := T[W]$ Is defined, and the SVD of $W = UDQ^T$ is $W$, then:

$$\hat{V}_k^c(j) = U_{(c-1)d+j,k}\sqrt{D_{k,k}} \quad (14)$$

$$\hat{H}_k^c(j) = Q_{(n-1)d+j,k}\sqrt{D_{k,k}} \quad (15)$$

Where $(\hat{H}, \hat{V})$ is the solution $P1$, and is the filter called a low-rank constrained filter?

The $32 \times 32 \times 32$ grid is used to represent the three-dimensional shape. After the three-dimensional decoding features are obtained, the Sigmoid activation function predicts the occupancy probability. The mathematical formula of the Sigmoid function is shown in Formula (16):

$$Sigmoid\,(x) = \frac{1}{1+e^{-x}} \quad (16)$$

All the calculations of hidden layers are changed to convolution operations to retain the ability to extract spatial neighbourhood relations by convolution calculation, and all the operations on input are all connected layers. After obtaining one-dimensional vectors, the fully combined layers are deformed into three-dimensional features, and the gate calculation with hidden layers continues.

## IV. ANALYSIS AND DISCUSSION OF RESULTS

A simulation test is carried out to verify the algorithm proposed in this paper. Hardware environment: Intel Core i7 2.8 GHz quad-core CPU, 8 GB memory. The simulation environment is Windows 7 operating system and Matlab simulation software.

According to the analysis of the network structure of SSD and MobileNet, in order to reduce the number of parameters and calculation of SSD and improve the detection rate, the lightweight MobileNet network can be applied to SSD. After that, four groups of convolution layers are added, and the output features of six convolution layers are extracted and fused to detect the target to be seen comprehensively. The added network structure of SSD MobileNet V2 is shown in Table I:

The experimental results of the training test data set used in this experiment are shown in Table II and Fig. 4. The speed of MobileNet is slower than that of SSD. Still, on the whole, the model size can be reduced to 15MB, and the rate is about 35 frames/s based on the SSD-fused MobileNet network with the same accuracy, so this algorithm makes it possible that target detection can be transplanted and applied to embedded and mobile devices.

TABLE I.  ADDED NETWORK STRUCTURE

| Input layer | Step length | Output channel |
|---|---|---|
| Conv2d_10 | 1 | 1280 |
| Conv2d_11 | 2 | 512 |
| Conv 2d 12 | 2 | 256 |
| Conv 2d 13 | 1 | 128 |
| Conv 2d 14 | 1 | 128 |
| Conv 2d 15 | 2 | 64 |

TABLE II.  EXPERIMENTAL RESULT

| Target class | SSD | SSD_MobileNet V1 | SSD_MobileNet V2 |
|---|---|---|---|
| Aeroplane | 0.7984 | 0.8477 | 0.8261 |
| Bicycle | 0.8394 | 0.8984 | 0.8035 |
| Bird | 0.8073 | 0.8515 | 0.8791 |
| Boat | 0.8088 | 0.7118 | 0.8321 |
| Bottle | 0.607 | 0.8897 | 0.9272 |
| Bus | 0.5985 | 0.7949 | 0.8898 |
| Car | 0.8023 | 0.7586 | 0.9221 |
| Cat | 0.7009 | 0.767 | 0.8466 |
| Chair | 0.6777 | 0.7896 | 0.8635 |
| Flower | 0.8837 | 0.8818 | 0.8539 |
| Tree | 0.7574 | 0.7462 | 0.8611 |
| Pavilion | 0.9332 | 0.7872 | 0.8758 |
| Streamlet | 0.6063 | 0.8177 | 0.8431 |
| Crowd | 0.6117 | 0.8975 | 0.864 |

In the process of plant growth, with the competition of individuals for available water, nutrients and light, individuals at a disadvantage gradually die, that is, self-thinning, also known as density-related death. The stand density calculated from the data of all sample plots in each year was used, and the overall regression analysis was carried out among the values of different density indexes to judge the similarity degree of other density indexes. The regression relationship between the stand density index and the Nilson density index shows some differences between the stand density index and the Nilson density index (see Fig. 5), which needs further analysis.

When the density index based on the self-thinning theory measures the uncultivated forest land, it will be larger than the recognized maximum density value to a certain extent, which makes the density index decrease in the late growth stage of the stand. Affected by natural disasters, this decline will start early or increase the number of unnatural death plants. Figure 6 reflects the Nilson density index of sample plots with the same initial density as shown in Fig. 6.

However, the density of Nilson reflects that the density of sample 1 with moderate site conditions in the previous N years is the highest, and the density of sample 3 with the best site index before the disaster is higher than that of sample 1. In different stages, the two density indexes show that the stand density of the medium and best site is the highest, indirectly indicating no obvious linear relationship between density and site index.
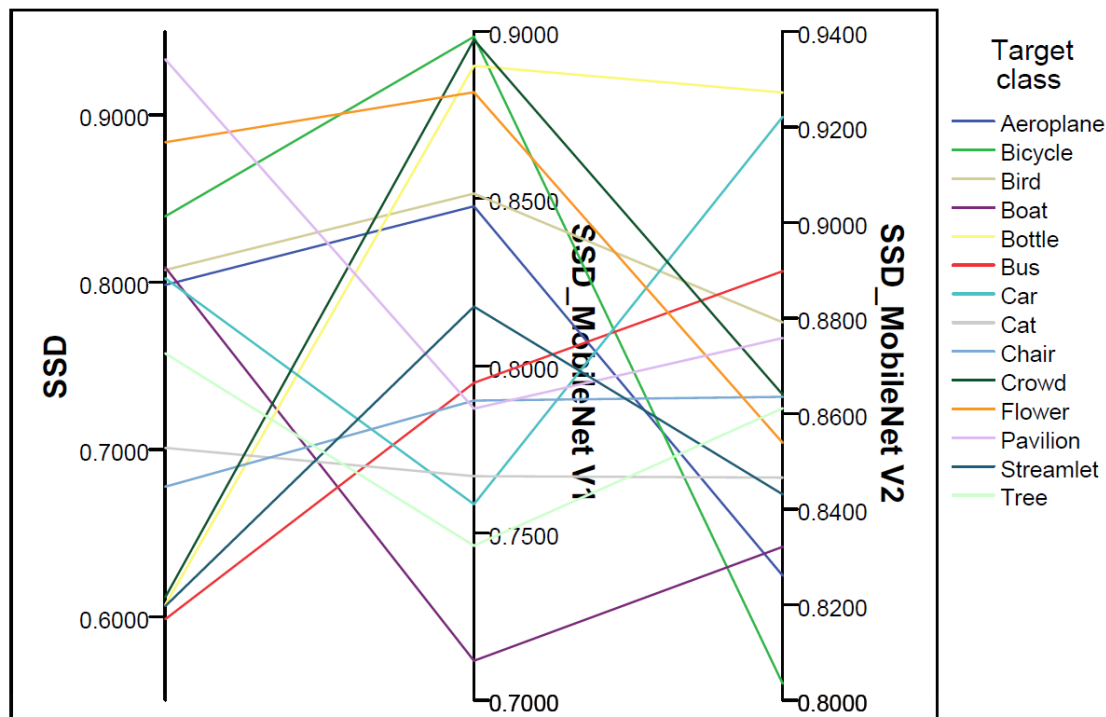


Fig. 4.  Experimental results can be viewed.
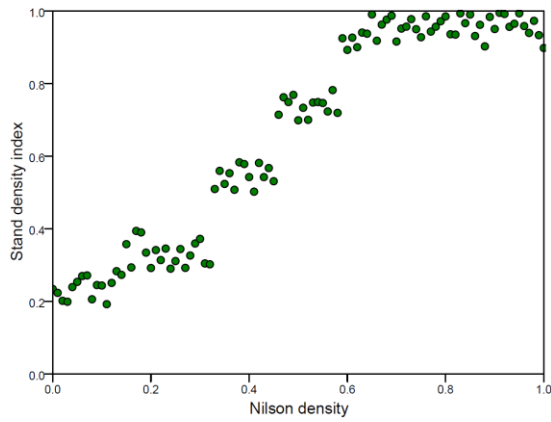
Fig. 5.    Relationship between stand density index and nilson density.
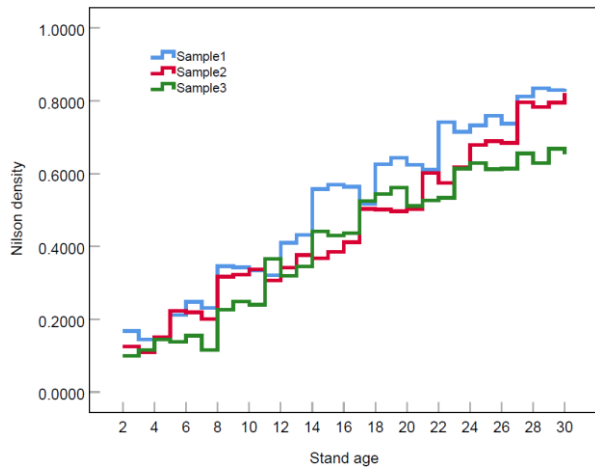


Fig. 6.    Nilson density index of sample plots with the same initial density.

After three stages of training, the 3D object voxel modeling system based on the lightweight DL model can dynamically obtain the optimal visual angle around the object to be reconstructed and the corresponding visual information under the visual angle, and finally reconstruct the 3D voxel through the object reconstruction module. To evaluate the reconstruction quality, IoU (Intersection over Union) is used for quantitative comparison. The experimental results are shown in Fig. 7 and Fig. 8.
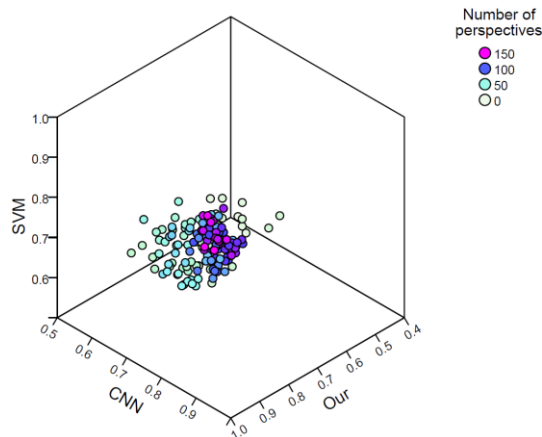


Fig. 7.    IoU values of reconstructed voxels with different perspective prediction methods.
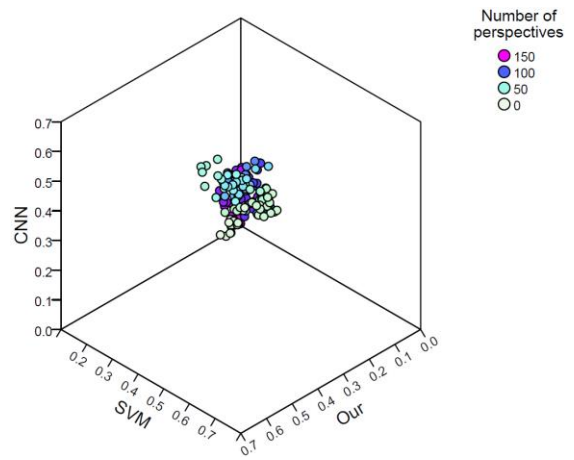


Fig. 8.    Information acquisition with different perspective prediction methods.

It can be seen that with the increase in the number of perspectives, the perspective sequence predicted by the network is planned with the perspective of this paper, and the reconstruction quality increases faster, which shows that the method of this paper can obtain more information suitable for object reconstruction and help improve its reconstruction quality. In this paper, the Shannon entropy of the perspective planning network decreases the most, which indicates that more new information can be acquired from the perspective of prediction, thus verifying the information acquisition ability of the network.

Table III shows the results of semantic segmentation, and Fig. 9 shows the accurate comparison between SVM, CNN and three different upsampling structures of this method. By comparing the values of these three upsampling structures, it can find that the pixel accuracy, average accuracy and average IU value of this method are the highest, with pixel accuracy as high as 90.44%, average accuracy as high as 93.15% and average IU value as 92.72%.

TABLE III.    SEMANTIC SEGMENTATION RESULTS OF LANDSCAPE ELEMENTS

| Evaluating indicator | SVM | CNN | our |
|---|---|---|---|
| Pixel accuracy | 0.8377 | 0.8283 | 0.9044 |
| Average accuracy | 0.8474 | 0.9041 | 0.9315 |
| Average IU | 0.8734 | 0.8964 | 0.9272 |

Landscape planning and design are faced with a comprehensive and complex system. Although the system itself is unique, the components of the system are changeable, and the change of a certain variable will have a series of changes, thus affecting the whole system. Accordingly, each element in the system does not exist in isolation, and each element is in a certain position and plays a specific role in the system. The elements are interrelated and form an inseparable whole. Because of the multi-objective design, it has the attribute of a system, that is, the integration and optimization of parameters in the system. It should be noted that the result of system simulation is not planning itself but provides the possibility of open thinking for various possibilities of planning and design.
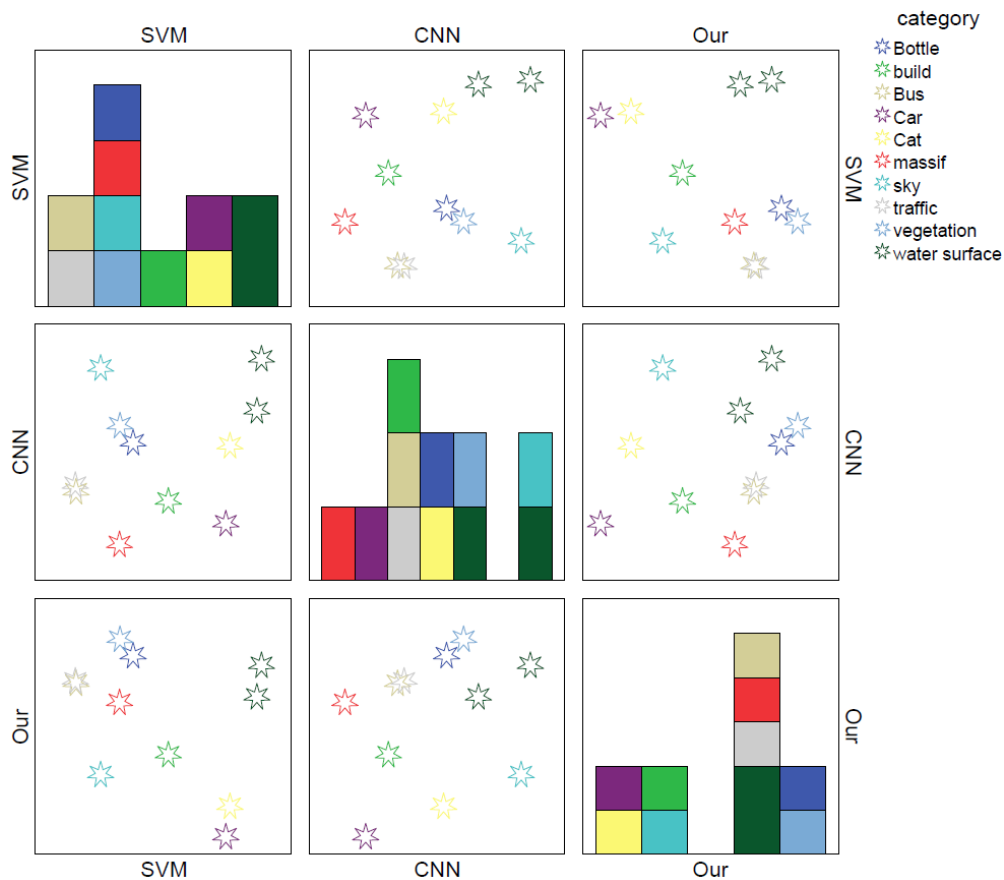
Fig. 9.    Accuracy distribution of landscape element classification.

The urban environment in any period will reflect the level of scientific and technological development in that period and the aesthetic consciousness of the times and these restrictions will restrict the manifestation of the environment. The rational application of science and technology can make the created environment personalized, establish a modern expression technique that runs through the design from beginning to end, and form a unified expression style with the times. Reconstruct the spatial form of land parcels with modern gardening methods and unique spatial processing techniques, among which organizing garden space with an axis is a common design technique. The space axis can well reflect the value of space, and different space types can be organized together through the axis to form a complete spatial sequence for the viewer.

## V.  Conclusion

The discipline of landscape architecture is developing daily, and the industry is in a rapid development stage, bringing unprecedented opportunities and prosperity to landscape architects. With the development of the social economy and the improvement of people's spiritual level, more attention has been paid to environmental quality. Landscape planning and design is a discipline integrating space art and time art, and landscape works, as an aesthetic entity, also exist in space and time simultaneously. Scientific intervention, adjustment, planning and design of landscape environment through parametric method is an important development direction and research difficulty of modern landscape architecture planning and design. This paper presents the network model flow of the 3D object voxel modeling method based on the lightweight DL model. The stand density calculated from the data of all sample plots in each year was used, and the overall regression analysis was carried out among the values of different density indexes to judge the similarity degree of other density indexes. In this paper, it can find that the pixel accuracy, average accuracy and average IU value are all the highest, with pixel accuracy as high as 90.44%, average accuracy as high as 93.15% and average IU value as 92.72%. Realize the integration and optimization of parameters in the system. It should be noted that the result of system simulation is not planning itself but provides the possibility of open thinking for various possibilities of planning and design.

In the future, deep learning technology can be utilized to better utilize historical design data and planning experience, providing designers with real-time and accurate decision support. For example, a recommendation system based on deep learning can help designers find similar or better design solutions from a large number of historical garden designs based on established design goals. With the development of deep learning technology, it can train models to automatically perform routine and repetitive design tasks, such as landscape layout, vegetation placement, etc., thereby freeing up designers' energy and enabling them to focus more on innovation and detailed design.

## REFERENCES

[1] L. Chen and Y. Wang, "Study on plant configuration and planning of landscape architecture in coastal cities," J Coast Res, vol. 115, no. SI, pp. 17–20, 2020.

[2] W. Fu, K. Yu, and D. Li, "Spatio-temporal relational evaluation of the Beijing water crisis and planning implementation from 1949 to 2013," Water Policy, vol. 20, no. 3, pp. 490–509, 2018.

[3] A. Altamirano et al., "Spatial congruence among indicators of recovery completeness in a Mediterranean forest landscape: Implications for planning large-scale restoration," Ecol Indic, vol. 102, pp. 752–759, 2019.

[4] A. C. Nelson and R. Hibberd, "Influence of Rail Transit on Development Patterns in the Mountain Mega-Region with a Surprise and Implications for Rail Transit and Land-Use Planning," Transp Res Rec, vol. 2675, no. 4, pp. 374–390, 2021.

[5] J. H. Thorne, H. Choe, R. M. Boynton, and D. K. Lee, "Open space networks can guide urban renewal in a megacity," Environmental Research Letters, vol. 15, no. 9, p. 094080, 2020.

[6] K. M. Parris et al., "The seven lamps of planning for biodiversity in the city," Cities, vol. 83, pp. 44–53, 2018.

[7] Ankita, S. Rani, H. Babbar, S. Coleman, A. Singh, and H. M. Aljahdali, "An efficient and lightweight deep learning model for human activity recognition using smartphones," Sensors, vol. 21, no. 11, p. 3845, 2021.

[8] S. B. Shuvo, S. N. Ali, S. I. Swapnil, M. S. Al-Rakhami, and A. Gumaei, "CardioXNet: A novel lightweight deep learning framework for cardiovascular disease classification using heart sound recordings," ieee access, vol. 9, pp. 36955–36967, 2021.

[9] Y. Yang et al., "A lightweight deep learning algorithm for inspection of laser welding defects on safety vent of power battery," Comput Ind, vol. 123, p. 103306, 2020.

[10] L. Wei, K. Ding, and H. Hu, "Automatic skin cancer detection in dermoscopy images based on ensemble lightweight deep learning network," IEEE Access, vol. 8, pp. 99633–99647, 2020.

[11] Q. Zhang, Q. Yuan, J. Li, Z. Yang, and X. Ma, "Learning a dilated residual network for SAR image despeckling," Remote Sens (Basel), vol. 10, no. 2, p. 196, 2018.

[12] Z. Li, Q. Zhang, T. Long, and B. Zhao, "Ship target detection and recognition method on sea surface based on multi-level hybrid network," Journal of Beijing Institute of Technology, vol. 30, no. zk, pp. 1–10, 2021.

[13] Y. Wang, J. Yang, M. Liu, and G. Gui, "LightAMC: Lightweight automatic modulation classification via deep learning and compressive sensing," IEEE Trans Veh Technol, vol. 69, no. 3, pp. 3491–3495, 2020.

[14] Z. Jiang, H. Zhu, Y. Lu, G. Ju, and A. Men, "Lightweight super-resolution using deep neural learning," IEEE Transactions on Broadcasting, vol. 66, no. 4, pp. 814–823, 2020.

[15] L. Deng, J. Li, and Z. Han, "Online defect detection and automatic grading of carrots using computer vision combined with deep learning methods," Lwt, vol. 149, p. 111832, 2021.

[16] R. Alharthi, A. Alhothali, and K. Moria, "A real-time deep-learning approach for filtering Arabic low-quality content and accounts on Twitter," Inf Syst, vol. 99, p. 101740, 2021.

[17] M. Tzelepi and A. Tefas, "Improving the performance of lightweight cnns for binary classification using quadratic mutual information regularization," Pattern Recognit, vol. 106, p. 107407, 2020.

[18] J. Hu, B. Liang, and X.-J. Qiu, "Transparent and ultra-lightweight design for ultra-broadband asymmetric transmission of airborne sound," Chinese Physics Letters, vol. 35, no. 2, p. 024301, 2018.

[19] F. Liu, K. Mao, H. Qi, and S. Liu, "Real-time long-term correlation tracking by single-shot multibox detection," Optical Engineering, vol. 58, no. 1, p. 13105, 2019.

[20] X. Zhu et al., "Single-shot multi-view imaging enabled by scattering lens," Opt Express, vol. 27, no. 26, pp. 37164–37171, 2019.

[21] S. Han, Y. Jiang, Y. Huang, M. Wang, Y. Bai, Spool-White, A. "Scan2Drawing: Use of Deep Learning for As-Built Model Landscape Architecture," Journal of Construction Engineering and Management, vol. 149, no. 5, pp. 04023027, 2023.

[22] J. Bzai, F. Alam, A Dhafer, M Bojović, S. M. Altowaijri, Niazi, I. K., & Mehmood, R. "Machine Learning-Enabled Internet of Things (IoT): Data, Applications, and Industry Perspective", Electronics, vol. 11, no. 17, pp. 2676, 2022.

[23] X. Wang, J. Yi, J. Guo, Y. Song, J. Lyu, J. Xu, H. "Min A review of image super-resolution approaches based on deep learning and applications in remote sensing", Remote Sensing, vol. 14, no. 21, pp. 5423, 2022

# Investigations of Modified Functional Connectivity at Rest in Drug-Resistant Temporal Lobe Epilepsy Patients

Deepa Nath[1], Dr. Anil Hiwale[2], Dr. Nilesh Kurwale[3], Dr.C.Y.Patil[4]

School of ECE, Dr.Vishwanath Karad MIT World Peace University, Pune[1, 2]

Neurosurgeon, Deenanath Mangeshkar Hospital, Pune[3]

Dept of Instrumentation and Control, COEP Technological University, Pune[4]

*Abstract*—**In this experimental study patients with temporal lobe epilepsy and controls have been compared for functional connectivity (FC) using resting-state functional magnetic resonance imaging (rs-fMRI). This research work examines the alterations to better understand the issues with brain activity of individuals suffering from Temporal Lobe epilepsy (TLE), during the rest state. The major objective of this study is to investigate FC-related alterations in the resting state to fully comprehend the complex nature of epilepsy. It is** observed that FC gets altered in specific regions in the case of patients suffering from left-sided Temporal Lobe Epilepsy and right-sided Temporal Lobe Epilepsy as compared to controls. Using rs-fMRI, it is found that the right-sided TLE patient group had altered hippocampus networks than the control right-side group. There are considerable differences between the left and right areas of control and the groups with mesial temporal hippocampal sclerosis on the left and right sides. When compared to control left brain regions, the left-side TLE group exhibits reduced connection between the anterior cingulate gyrus and the affected hippocampus and increased regional connectivity between the affected hippocampus and the default posterior cingulate cortex region.

*Keywords*—*Temporal Lobe Epilepsy (TLE); resting-state Functional Magnetic Resonance Imaging (rs-fMRI); Functional Connectivity (FC); Blood Oxygen Level-Dependent (BOLD)*

## I. INTRODUCTION

Over the past few years, resting-state Functional Magnetic Resonance Imaging, (rs-fMRI), has been used. The rs-fMRI studies of the human connectome have gained popularity, and these studies are extremely valuable for understanding epilepsy networks and improving surgical treatment. Surgery to remove epileptogenic tissues may be a successful course of treatment for 20– 30% of epilepsy patients whose seizures are unresponsive to medication [1]. The most successful method for treating drug-resistant epilepsy is surgery. After thorough presurgical evaluation, seizure freedom can be achieved in approximately 60- 70% of patients [2].

FC of a brain network explains the patterns and degree of temporal correlations of activation patterns across distant brain regions. FC is a metric for the understanding relationship between different brain areas. A significant portion of the current work is based on assumptions regarding which parts of the brain are active when it is at rest. This calls

for monitoring the relative changes of Blood Oxygenated level-dependent (BOLD) signal in comparison to the baseline in different brain regions when it is at rest [3]. Emerging neuroimaging research generally supports the idea that resting-state BOLD variations are at least largely caused by intrinsic brain activity [4, 5]. Consequently, investigations on spontaneous regional interactions happen when the brain is at rest. Epilepsy in the mesial temporal lobe (MTLE) is studied extensively for clinical characteristics and neuropsychological deficits [6, 7].

TLE is associated with various neuropsychological deficits beyond the boundaries of the temporal lobe and apart from memory; other common deficits associated with TLE include the domains of executive function, language, and cognition [4]. Right and left TLE presents visual and verbal memory deficit profiles, which were traditionally used for lateralizing the epileptogenic lesion however; overall neuropsychological deficits were more common with left TLE patients [4]. Moreover, the dominance of the lobe is known to affect the pattern of neuropsychological deficits but the extent of deficits alwaysremains unpredictable.

However, the right and left TLE differ in language, executive function, and social cognition, according to neuropsychological literature on TLE, which is the clinical expression of functional connection. The work presented in the paper aims to examine the variations in resting-state connection networks in well-matched cohorts of patients with right- and left-sided TLE and to compare them to healthy controls in the respective regions of the right and left brain.

Low-frequency neural oscillations have been the subject of novel rs-fMRI research [5] that has progressed in the neuroscience literature. [3,4]. Functional connections of various brain regions using rs-fMRI help explain TLE's neuropsychological deficits [6, 7, and 8]. Most of the methods of the rs-fMRI utilize group analysis using various algorithms and pipelines [9] where different preprocessing steps are applied and signals are averaged for the group and plotted.

Numerous epilepsy network investigation studies [10, 11, and 12] have examined groups with left and right-side involvement. In several studies, the Left TLE (LTLE) or Right TLE (RTLE) is compared to the Healthy Control group. The unique feature of this experiment is that regions related to the

right-side memory circuits of the Control and the right-side TLE groups are compared, and comparable comparisons were made for the left-side group. The functional connectivity between regions of interest (ROI) inside and outside the epileptogenic network was assessed in the right or left regions of patients with treatment-resistant RTLE or LTLE and control participants, respectively. The introduction is mentioned in Section I, the dataset and methods are described in Section II, analysis and results obtained during experimentation are discussed in Section III, the results obtained and their comparison to the work of other researchers are discussed in Section IV, the limitations and future directions of the study are discussed in Section V, and the conclusion is stated in Section VI.

## II. MATERIAL AND METHODS

### A. Study Period

MRI data collection for patients and controls was done for the period of the past two years from 2021 to year 2022.

### B. Participants

Patients with temporal lobe epilepsy who are drug-resistant, with unilateral hippocampal scleroses that were deemed candidates for standard anterior temporal lobectomy and amygdalo hippocampectomy formed the patient group. All the patients had the scans on a single magnetic resonance imaging Siemens make 3T MRI scanner (Skyra). Left and right TLE groups of patients were separated. Separately data was generated for the control group. Our study sample includes right TLE (n=07), left TLE (n=09), and controls (n=16), which makes a total of 32 participants. Demographic data is mentioned in Table I.

### C. Ethical Standards

The present study is approved by the Independent Institutional Review Board (IRB) for all the components of the study. All the ethical practices have been followed while the study is been carried out. Informed consent was taken from all participants.

TABLE I. SUBJECT-SPECIFIC DEMOGRAPHIC DATA

| Subjects | Controls | LTLE | RTLE |
|---|---|---|---|
| N (Male, Female) | 16 (15, 1) | 9 (5, 4) | 7(5, 2) |
| Mean age (years) | 20.83 | 20.87 | 26.14 |
| Epilepsy Duration in years(mean±SD) | | 8.85±5.87 | 14.85±13.04 |
| Antiepileptic Drugs(AED) (mean±SD) | | 2.57±0.53 | 3±0.69 |
| Seizure frequency/month(mean±SD) | | 1.6±1.54 | 1.16±0.408 |

### D. MRI Data Acquisition Parameters

*1) Patient conditioning:* Before the start of the resting state acquisition, patients were advised to recline comfortably with their eyes closed as the regular epilepsy surgery scanning was conducted on a single scanner.

*2) Structural T1 data:* High-resolution structural data which is used to quantify brain structure sequence was acquired in 256x256 matrix, 3D acquisition without any gap with a slice thickness =0.5 mm, echo time = 3.07ms, Repetition time (TR) = 3000 ms, and flip angle= 8∘ with voxel size was 0.5x0.5x0.5 mm

*3) Functional data:* It is employed to research brain activity. BOLD data was acquired in a one-shot gradient echo-planar imaging sequence with parameters in a single direction. A total of seven minutes and 140 volumes of a sequence were recorded using a flip angle of 90 degrees, a repetition time of 3000 ms, and an echo time (TE) of 30 ms.

### E. Imaging

With the aid of a 3T MRI system (Siemens), imaging was carried out. The following settings were used for functional imaging: repetition time (TR) = 3000 msec, echo time (TE) =30 msec, slice thickness = 2 mm, and 36 slices. The same imaging investigation produced high-resolution structural pictures. fMRI recordings, each lasting seven minutes, were made during the imaging sessions.

### F. Pre-processing

Regions of interest (ROI) default for 164 regions were created from T1 scans in the CONN toolbox [13] and used Harvard-Oxford Atlas [14]. All volumes were segmented, and normalized, slice time was adjusted, co-registered to T1, and realigned to the first functional scan using the Montreal Neurological Institute (MNI) 152 template.

The head movement artifacts are eliminated, high-pass filtering is applied for 100 s, and spatial smoothing is performed at 8 mm full-width half-maximum. The SPM12 (statistical parametric mapping) is used for preliminary data processing for each patient. The procedures for realignment and slice-time adjustment are standard and CONN uses the Artifact Detection Tools (ART) to look for outliers. Direct normalization in [15] is the method we choose to utilize to normalize the standard template of MNI152 space. After performing structural segmentation and normalization, the BOLD signal-to-noise ratio is then improved using a Gaussian kernel with an 8mm full width at half maximum(FWHM).

### G. Denoising

Physiological, head-motion and other sources of noise must be reduced to focus on low-frequency oscillations while reducing their overall volume, BOLD data are filtered in the temporal domain using a band-pass filter of 0.008 to 0.9 Hz before further processing. To decrease the influence of variation of FC values is measured between pairs of randomly selected ROIs in the brain to gauge the effectiveness of the procedure (see Fig. 1 for a specific Subject 1).

### H. First-Level Analyses

To describe the functional connectivity between each pair of areas, ROI-to-ROI connectivity (RRC) matrices [16] were calculated. The correlation coefficient's sample distribution, or Pearson's r, can be transformed into a normally

distributed distribution using the Fisher Z-Transformation. The level of functional connectivity is measured using Fisher-transformed bivariate correlation coefficients from a general linear model (weighted-GLM) [17], as stated in (1) which were independently computed for each pair of ROIs and characterized the relationship between their BOLD signal time series. Refer to Fig. 2 for the first-level analyses.

The analyses for this study examined the ROI-to-ROI connections between brain regions for memory circuits. It is limited to a particular set of 12*12 connections (refer to Table II) out of all available connections (164x164). The degree of connectivity between each pair of ROIs among a pre-defined region RRC. Using this selected list of ROI, as described in Table II, an investigation for individual differences wascarried out for RTLE, LTLE, and controls.

$$r(i,j) = \frac{\int R_i(t)dt\, R_j(t)dt}{\int (R_i^2(t)dt\, R_j^2\,(t)dt\,)^{1/2}} \tag{1}$$

$$Z\,(i,\ j) = \tan h^{-1}(r\,(i,j)) \tag{2}$$
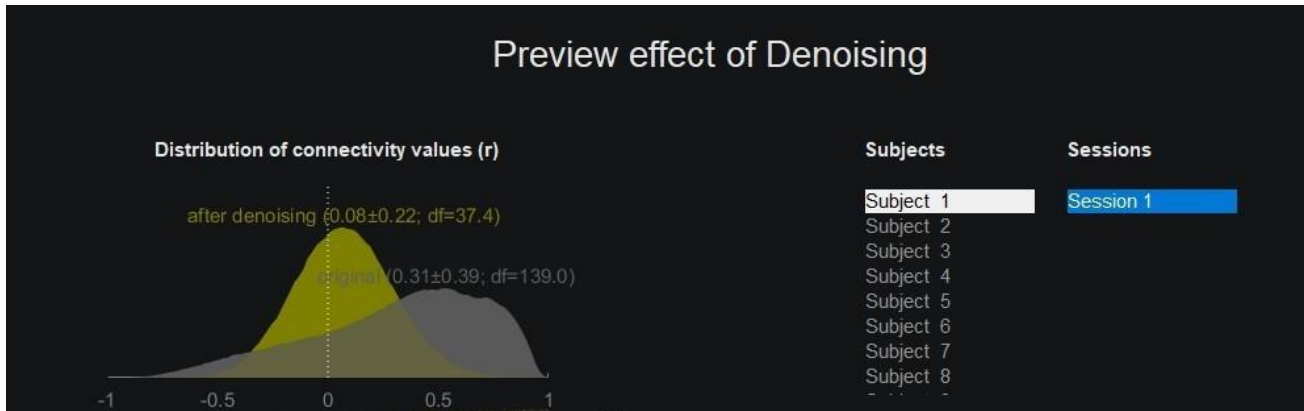


Fig. 1. Denoising effect for a particular subject.
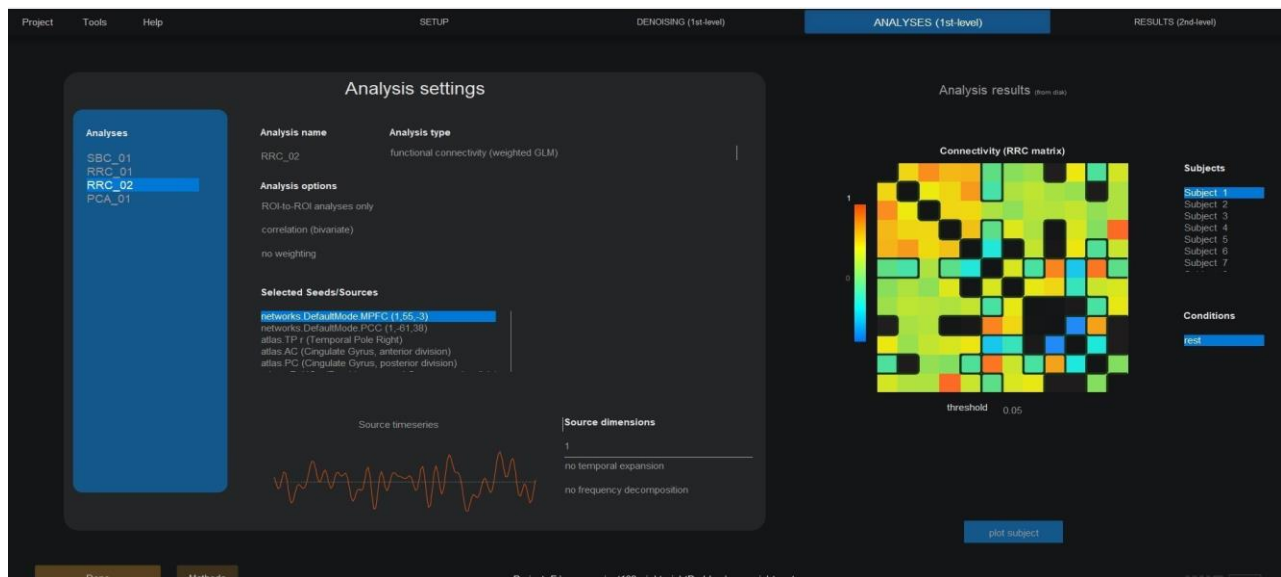


Fig. 2. First level analysis GUI display on CONN toolbox [16].

where R is the BOLD time series inside each ROI, Z is the RRC matrix of Fisher-transformed correlation coefficients,r is a matrix of correlation coefficients(see (2)), and Z is the matrix of Fisher-transformed correlation coefficients (all-time series are assumed to be centered to zero mean here for simplicity). In the first level of analysis we need to choose the method of connectivity like Seed-based connection (SBC) or Region Re gion Connectivity (RRC), Principal Component Analysis, and many more. For this study, 12 ROIs are compared for connectivity analysis as listed in Table II. As a result, connectome rings appear on the

CONN Graphical User Interface (GUI), and the variations between them were quantified visually.

### I. Group/Second Level Analysis

Second-level analyses are used to draw conclusions about the characteristics of groups or populations. CONN uses the General Linear Model (GLM) [17] to examine functional connectivity data at the second level.

Selecting one or more items from the "Subject effects" list and indicating the desired 'between-subjects contrast' establishes a second-level model in CONN. Control and

Patients are the two groups designated in this experiment, and they are originally listed in the covariates tab during setup and enter [1 -1] to evaluate the differences between the groups 'connections. Otherwise, just enter [1 0] or [0 1] and refer to Fig. 3 in the 'Between-Subject Contrast' to understand the individual effects of Controls or Patients independently. The evaluation of the connection-level hypothesis uses multivariate parametric statistics with random effects across participants and sample covariance estimates across different data. The inferences were analyzed on a per-cluster basis (groups of linked connections). Based on parametric statistics between and within each pair of network-level identifiers as independent variables, cluster-level inferences were made. Refer to Fig. 3 for Second Level Analysis. Functional Network Connectivity [13], which employs complete-linkage hierarchical clustering and the ROI-to-ROI physical closeness and functional similarity metrics [16], to discover networks. Results were threshold using a family-wise adjusted p-FDR= 0.05 cluster-level Threshold [18] in addition to a p= 0.05 connection-level threshold [19].The results of the first-level studies of each individual are combined at this stage to analyze the total population. When conducting group-level analysis, the effect estimates of the General Linear Model are frequently combined across participants using the t-test, ANOVA, ANCOVA, multiple regression, or linear mixed-effects (LME) models. The subject-effects (X), conditions (Y),

between-subjects contrast (C), andbetween-conditions contrast (M) matrices are the only ones that must be specified for the GLM framework. As a result,the same GLM framework can be used to specify a very wide range of traditional analyses.

TABLE II.    SELECTED ROI FOR COMPARISON WITH RTLE, LTLE, AND CONTROLS

| Sr.No | Region of Interest | Abbreviations |
|---|---|---|
| 1. | Default Mode.The medial prefrontal cortex (MPFC) | MPFC |
| 2. | DefaultMode.Posterior cingulate cortex(PCC) | PCC |
| 3. | Temporal Pole affected | TP r/l |
| 4 | Cingulate Gyrus, anterior division | AC |
| 5 | Cingulate Gyrus, posterior division | PC |
| 6 | Parahippocampal Gyrus, anterior division affected | aPaHC |
| 7 | Parahippocampal Gyrus, posterior division affected | pPaHC |
| 8 | Planum Temporal affected | PT r/l |
| 9 | Hippocampus affected | Hippo r |
| 10 | Hippocampus contralateral | Hippo l |
| 11 | Amygdala affected | Amy r/l |
| 12 | Insular Cortex affected | IC r/l |
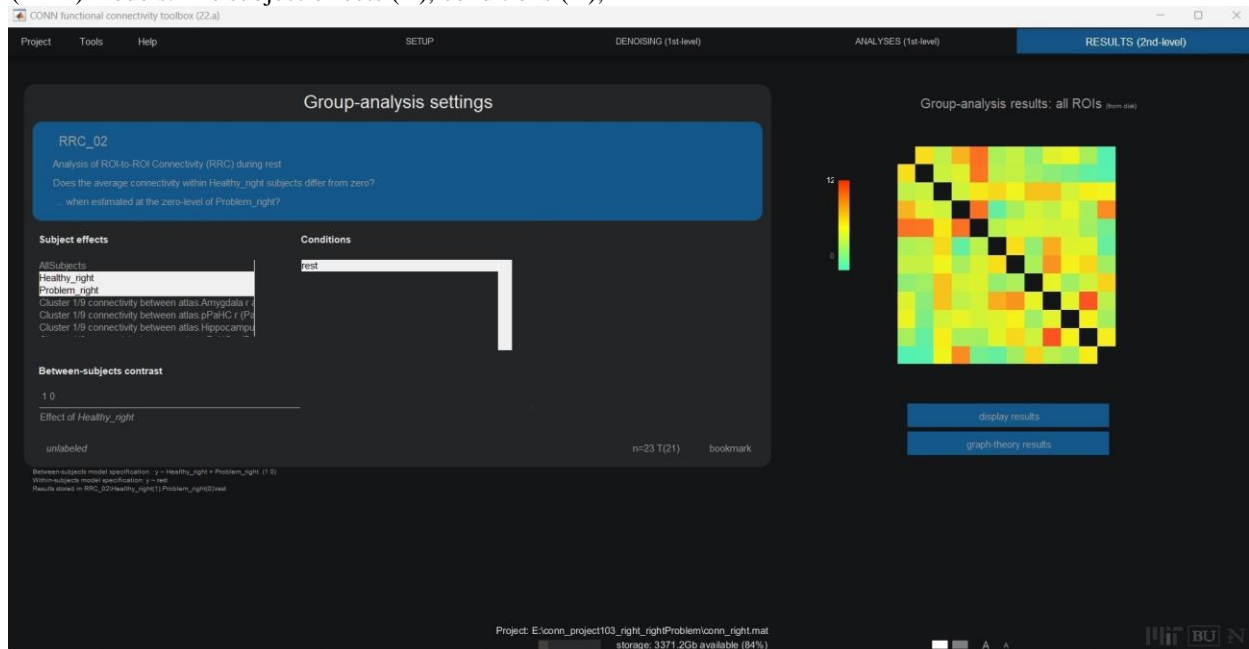


Fig. 3.    Second-level analysis for group level [16].

## III. ANALYSIS AND RESULTS

The analysis is performed on the CONN toolbox, 2022a [13], an SPM-based toolbox that runs on MATLAB 2022a. Two groups were used for the intergroup comparisons: Healthy_l controls for the left side regions of the brain with patients who had LTLE, and Healthy_r controls for the right side parts of the brain with patients who had RTLE. To further investigate the results, all the data is plotted on connectome rings and brain templates. Default Color coding is used to

interpret the connection strength, from the blue to red spectrum where blue is negative and red is an extremely positive correlation or connectivity amongst the ROIs. The second-level results tab of CONN generates a ROI.mat file after processing the images. The intriguing results in this file can be used to draw a conclusion. Here, names provide a list of ROI sources, h value provides the Fisher transformed correlation value based on the particular contrast used during the experiment, F values show the value of the statistic, and P values provide one-sided tail values.

The ROI.mat files produced during the second level analysis can be used to generate graphical results visualization in CONN GUI. Ring Connectome results for the ROI to ROI connections as specified in Table II are displayed. Both graphical visualizations of group-level analysis are compared with the help of ring connection display and RRC matrix.

The data displayed on the ring connectome is as shown in Fig. 4. The 3D brain view displayed in Fig. 5 can be viewed in the same Conn GUI. As shown in Fig. 4, there are apparent differences in the correlation values between Healthy_r and other ROI in the RTLE group. As seen in Fig. 5, the medial prefrontal cortex (MPFC) and posterior cingulate cortex (PCC), two of the default mode networks with the contralateral hippocampus, are no longer connected to one another. Also in the RTLE group, the amygdala and hippocampus both lack connections to the anterior cingulate and PCC regions, respectively. The RRC matrix, which is accessible through the CONN GUI, only outputs color variations between various pairs of ROI. With the help of Python code and the h, F, or P values from the ROI.Mat file, distinct RRC matrices can be produced. Here, the RRC matrix is made using h values, and the correlation values are displayed in the boxes for comparison between the affected RTLE patients and the control group (see Fig. 6).

The 12 interest ROIs are taken into account (see Table II). Additionally, two sample t-tests were run in the second-level analysis to compare the Controls and RTLE groups. In the results explorer GUI's customize menu, under the advanced Family Wise Control Settings, the connectivity threshold set to p< 0.05 and cluster threshold p< 0.1, as shown in Table III.

A plot of Effect Size is displayed in Fig. 7 about clusters of interest. Effect size is the measure of connection, which is commonly shown by Fisher-transformed correlations. From Fig. 7, the default mode posterior cingulate cortex (PCC) connectivity to the impacted Planum Temporal differs between the right TLE and the healthy control right areas of the brain. While this connection is absent in the control right-side memory network regions, significant connectivity between these anterior parahippocampal regions and the temporal pole is observed in RTLE.

TABLE III.    DIFFERENCES IN CONNECTIVITY VALUES

| Sr.No | ROI Region connections | Tstat, p-value |
|---|---|---|
| 1 | ROI 1/12 PCC to PTr | 3.16,p=0.004 |
| 2 | ROI 3/12 PC –AC | 2.89,p=0.008 |
| 3 | ROI 3/12 Hippo-left –AC | 2.39,p=0.02 |
| 4 | ROI 3/12 PC-PTr | 2.39,p=0.02 |
| 5 | ROI 3/12 aPaHC-PTr | -2.40,p=0.02 |

Similar to this, functional connectivity was compared between the Healthy Left Controls and the LTLE patient group. The results displayed on the ring connectome in Fig. 8 can also be viewed in a 3D brain perspective using the same Conn GUI. From Fig. 9, visually what can be observed is in the control group left all the selected ROIs are connected with other ROIs, whereas in the LTLE group, the connections with other ROIs are altered, prominently default

mode networks like medial prefrontal cortex (MPFC) and Posterior Cingulate Cortex (PCC) have connectivity with the affected temporal pole (TPl) and affected Planum Temporal (PT l). Also, the AffectedHippocampus is not connected with the Anterior Cingulate Gyrus.The correlation values heat map is plotted as shown in Fig. 10 for comparing Healthy left side regions of the brainwith the LTLE patient group based on correlation values.In addition, by selecting Subject Effects as both Healthy l andLTLE groups in Second Level Analyses, we attempted to doa two-sample T-Test for the comparison within two groups Healthy left side regions of the brain and LTLE impactedgroup. Similar settings were used like the right side comparison. A plot of Effect size referred to Fig. 11 concerning clusters of interest is shown. Effect size –is the magnitude of connectivity typically Fisher transformed correlations are displayed. Refer to Table IV for Connectivity differences, Fig. 11, the differences observed are listed.

TABLE IV.    CONNECTIVITY DIFFERENCES

| Sr.No | ROI | Region | Tstat, p-value |
|---|---|---|---|
| 1 | ROI 2/12 | PCC to AC | 2.47,p=0.02 |
| 2 | ROI 2/12 | Left Hippocampus -AC | 2.30,p=0.03 |

Differences noted in this intergroup comparison are when compared to the Healthy Control left side regions to the left TLE's- default mode network (PCC) connectivity to the Cingulate Gyrus' anterior division is noticeably different. Also when compared to healthy control left regions the connectivity of the affected hippocampus region with the Anterior CingulateGyrus (AC) dramatically diminished in LTLE.

## IV. DISCUSSION

### A. Alterations Observed in the RTLE Group with Control Right Regions

The results of the experiment as shown Fig. 6 reveal that RTLE patients showed less connection between the affected Planum Temporal, affected Hippocampus, and contralateral Hippocampus with Default Mode MPFC area. Also, it was discovered that the Planum Temporal and Affected Hippocampus in the RTLE group exhibited decreased connection for the Default mode PCC region. Additionally, RTLE revealed a weakening of the connection between the anterior division of the cingulate gyrus and the contralateral hippocampus. Also, the posterior cingulate gyrus showed a weaker connection with the contralateral hippocampus.

### B. Alterations Observed in the LTLE Group with Control Left Regions

With reference to Fig. 10, it is observed that there is a weak link between the afflicted hippocampus and the Amygdala with the default mode MPFC when LTLE patients were compared to groups of healthy control left region. Also discovered that in LTLE group anterior cingulate gyrus has a decreased connectivity with the affected hippocampus. A stronger link between the injured and contralateral hippocampi and the PCC in default mode was also seen. A weakened connection between the Planum Temporal affected with Amygdala is observed in LTLE as compared to the control group.
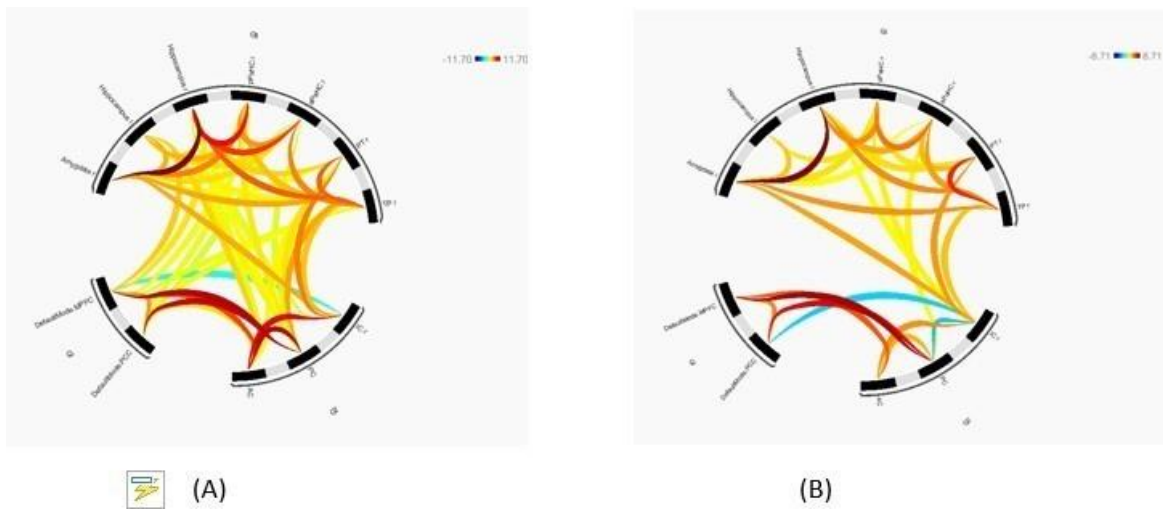
Fig. 4.   Ring connectome comparison (A) Healthy_r with (B) RTLE.
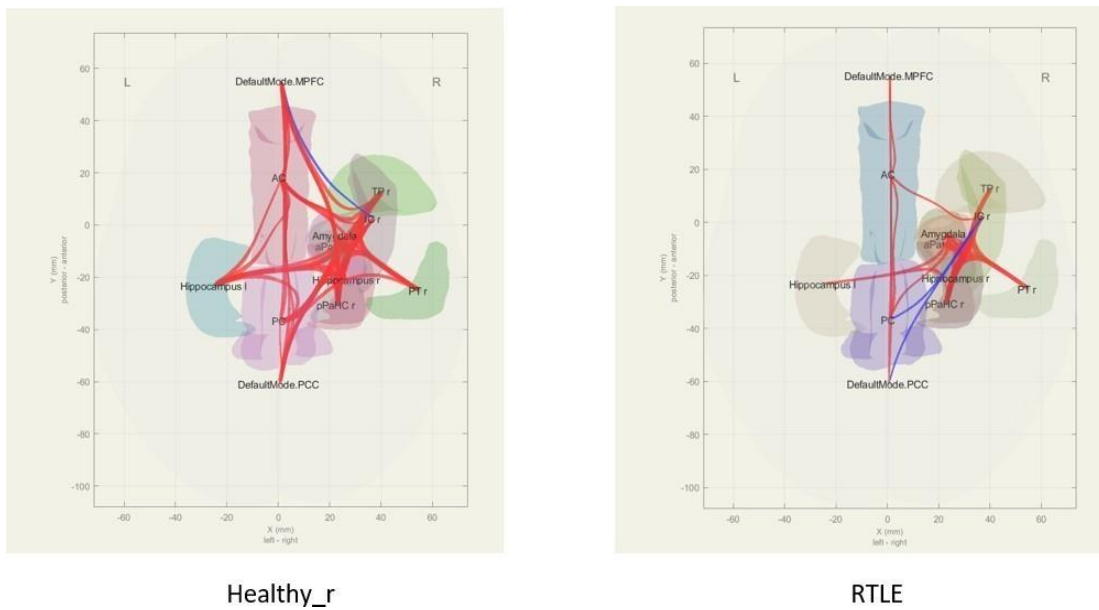


Fig. 5.   Healthy⌐r versus RLTE results on 3D brain view.
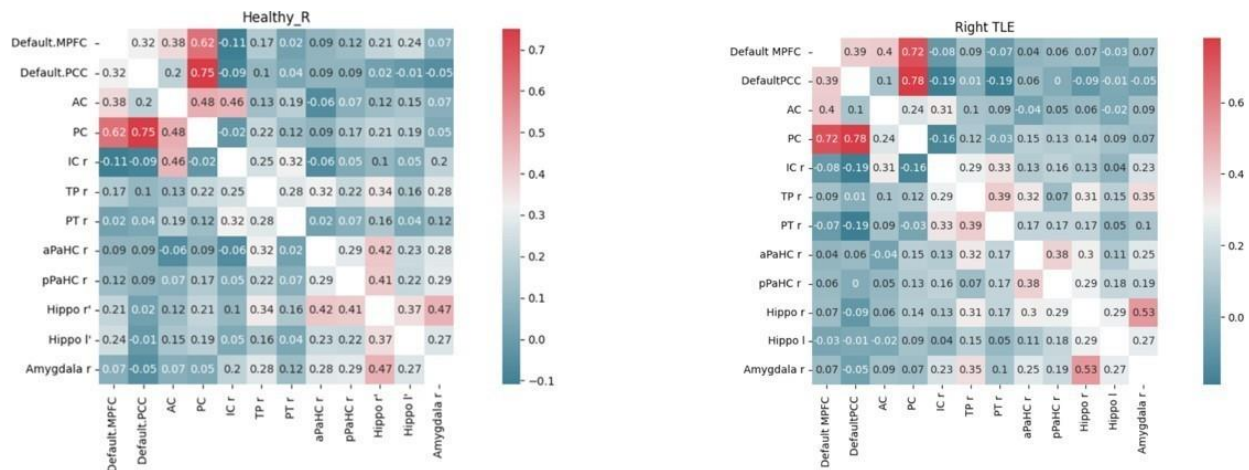


Fig. 6.   Correlation values for healthy versus RTLEmatrix values display. Heatmap is created based on fisher transformed correlation coefficient based on python version 3.10.

Fig. 7.   Plot Effects –average effect sizes with the selected clusters.

## C. A Few Relevant Case Studies

Haneef et al. [20] in their study of LTLE 13 patients, RTLE 11 patients, and 16 healthy controls also report similar findings, wherein Default mode connectivity gets more affected in TLE patients, Default mode Network with the hippocampi. Pierera et al. [21] in their study of ROI-ROI analysis of 18 patients and nine healthy controls report asymmetrical loss of connectivity between left and right Hippocampus Sclerosis in a similar fashion but the authors only studied hippocampal seed, unlike our study where all the other important connectivity profiles like DMN and memory networks are also explored.

In a study by Zhao, [22] involving 12 LTLE patients, 11 RTLE patients, and 23 healthy controls, functional connectivity differences were examined using ROI- based analysis. In this study, the LTLE group had a significantly lower link with the anterior and posterior parahippocampus gyrus compared to the controls. The reduced connection between areas in the bilateral temporal lobes and frontal lobes was also discovered on the right side. Pressl [23] et al. used rs-fMRI to investigate a potential link between TLE treatment response and functional network alterations. In individuals with treatment-resistant and well-controlled epilepsy, they looked at variations in functional connectivity between regions of interest (ROI) inside and outside the epileptogenic network. As suggested in their findings the thalomo-hippocampus positively correlated in Controls, while they are negatively correlated in treatment resistance TLE patients and this could serve as a new biomarker for TLE diagnosis and preventive treatment. In another study of Marine Fleury [24] where 43 controls and 29 TLE patients connectivity was studied, Patients with TLE had enhanced regional connectivity between the anterior Mesial Temporal Lobes (MTL) on both sides and widespread decreased connectivity between the frontal lobes and MTLs as compared to controls.

Another study by Barnett [25] found that in persons with temporal lobe epilepsy (TLE), the hippocampus's connections to other parts of the default mode network (DMN) are a reliable predictor of memory function. Using resting state fMRI data from individuals with left-sided TLE (LTLE) and right-sided TLE (RTLE), they divided the hippocampus based on its functional links to the rest of the brain, as well as from a set of neurologically healthy controls. Other Default mode Networks (DMN) regions are less connected to the medial prefrontal cortex (mPFC) and posterior cingulate cortex (PCC), two important sections of the DMN, were reduced in both TLE groups. The anterior region of the hippocampus in the LTLE group also displayed a decreased connection to the DMN. This is in line with the findings made in this experiment, which showed that the hippocampus-to-DMN connection can be used as a helpful marker for persons who have temporal lobe epilepsy. Future research will be useful in determining whether anterior and posterior biases in connection are associated with the impairment of more precise memory functions in TLE patients. The importance of these findings can also be understood with the use of clinical neuropsychology correlation. Here in this study for memory circuits, a selected group of ROI was chosen for analyses. This list of ROI can vary for different network studies.



(C.)



(D)
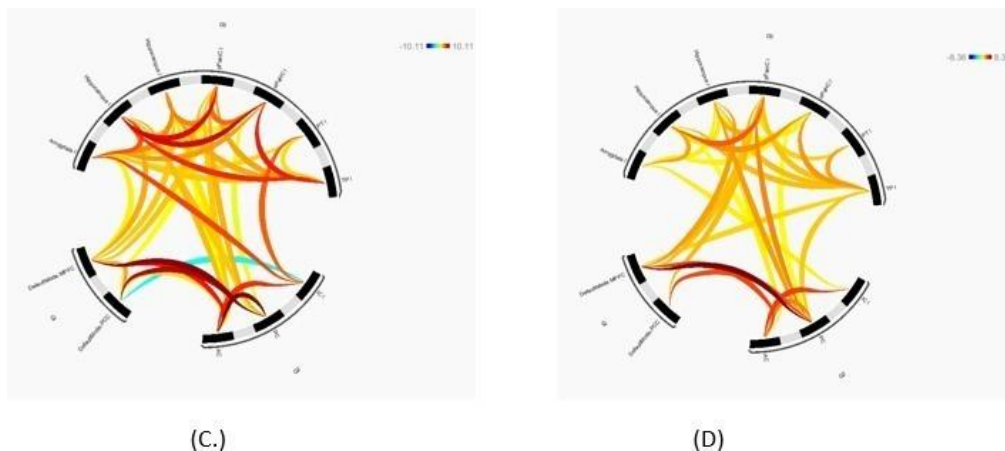
Fig. 8.   Ring connectome comparison (C) Healthy_l with (D) LTLE.
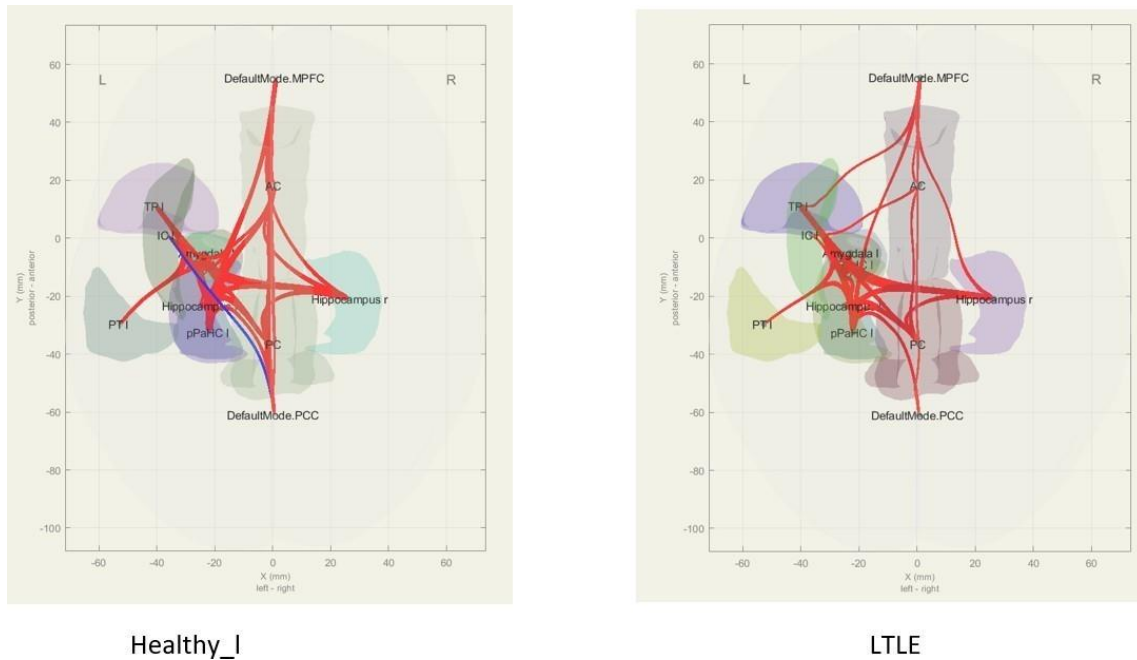
Fig. 9.   Healthy_l versus LTLE results on 3D brain view.
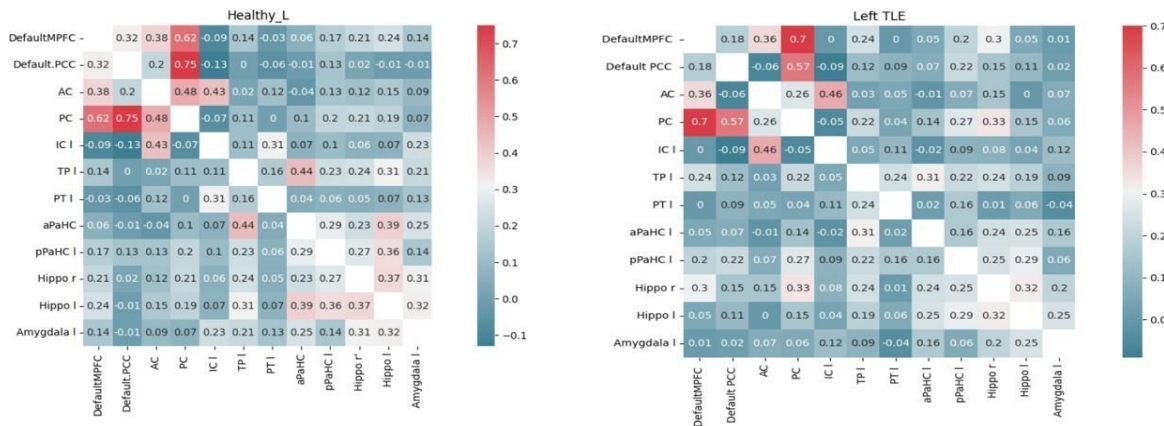


Fig. 10.  Correlation values for healthy versus LTLE matrix values display. A heat map is created based on Fisher transformed correlation coefficient.
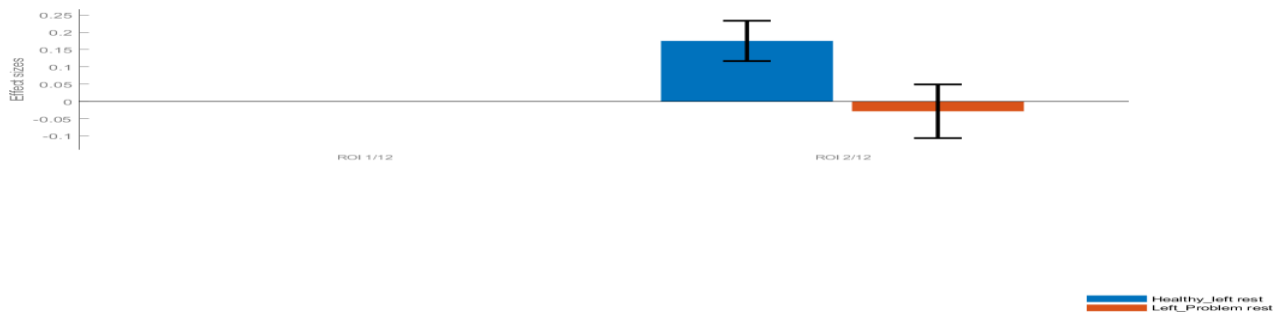


Fig. 11. Plot Effects–average effect sizes with the selected clusters.

## V.   LIMITATIONS AND FUTURE SCOPE

It is not that easy to generate the data for healthy subjects. In this study, data of 16 healthy controls was arranged with proper consent from the volunteers; however, a larger sample size may increase the accuracy of the analysis. The larger dataset may help to validate the variations in connections that are clinically relevant and correlated. It will help to characterize TLE patients and provide more information about neurologic abnormalities. Also with different sets of ROI selections, it can be expanded for attention, language, visual, motor, sensory networks, and many other networks of the brain.

## VI. CONCLUSION

The distinguishing feature of this experimental study is the comparison of right-side memory circuit-related regions of the control group with that of the right-side TLE group as well as the comparison of the left-side memory circuit-related regions of the control group with that of the left-sided TLE group. The mesial temporal hippocampus sclerosis patient group on the left and right sides exhibit distinct changes in the organization of the memory networks in comparison with the control group left and right sides. By comparing the RTLE patient group to the right-side Control group, the differences have been identified in the hippocampal network. The two default mode networks MPFC and PCC have weaker connectivity between the affected and contralateral hippocampi. In the LTLE patient group, reduced connections have been observed for impacted Planum Temporal and Default MPFC. Comparing LTLE to the control group for left brain areas, it has been observed that there was a decreased connection between the anterior cingulate gyrus and the affected hippocampus and more connectivity between the affected hippocampus and the default posterior cingulate cortex.

## REFERENCES

[1] C. Zhang and P. Kwan, "The Concept of Drug-Resistant Epileptogenic Zone", Frontiers in Neurology, Volume 10, pp. 558–558, 2019.

[2] J.-A. Witt, T. Krutenko, M. Ga¨deke, R. Surges, C. E. Elger, and C. Helmstaedter, "Accuracy of expert predictions of seizure freedom after epilepsy surgery," Seizure, vol. 70, pp. 59–62, 2019.

[3] K. A. Smitha, K. Raja, K. M. Arun, P. G. Rajesh, B. Thomas, T. R. Kapilamoorthy, and C. Kesavadas, "Resting-state fMRI: A review on methods in resting state connectivity analysis and resting state networks," Neu- roradiology J, vol. 30, no. 4, pp. 5 524 274–5 524 274, 2017.

[4] H. Lv, Z. Wang, E. Tong, L. M. Williams, G. Zaharchuk, M. Zeineh, A. N. Goldstein-Piekarski, T. M. Ball, C. Liao, and M. Wintermark, "Resting-State Functional MRI: Everything That Nonexperts Have Always Wanted to Know," ' American Journal of Neuroradiology, vol. 39, no. 8, pp. 1390–1399, 2018.

[5] B. Biswal, F. Z. Yetkin, V. M. Haughton, and J. S. Hyde, "'Functional connectivity in the motor cortex of resting human brain using echo-planar MRI'," Magn Reson Med, vol. 34, no. 4, pp. 537–578, 1995.

[6] W. Liao, Z. Zhang, Z. Pan, D. Mantini, J. Ding, X. Duan, C. Luo, Z. Wang, Q. Tan, G. Lu, H, and C, "Default mode network abnormalities in mesial temporal lobe epilepsy: a study combining fMRI and DTI," Hum Brain Mapp, vol. 32, no. 6, pp. 883–95, 2011

[7] Cataldi M, Avoli M, de Villers-Sidani E. "Resting-state networks in temporal lobe epilepsy", Epilepsia. 2013 Dec;54(12):2048-59.

[8] A. Barnett, S. Audrain, and M. P. Mcandrews, "Applications of Resting-State Functional MRI Imaging to Epilepsy," Neuroimaging Clin N Am, vol. 27, no. 4, pp. 697–708, 2017.

[9] D. Nath, A. Hiwale, and N. Kurwale, "'Optimization of Pipeline through Preprocessing Steps Sequence Alteration using Graph Theory for Resting-State fMRI," International Journal of Engineering Trends and Technology, vol. 71, no. 3, pp. 168–174, 2023.

[10] C. Fu, A. Aisikaer, Z. Chen, Q. Yu, J. Yin, Yang, and W, "', Different Functional Network Connectivity Patterns in Epilepsy: A Rest-State fMRI Study on Mesial Temporal Lobe Epilepsy and Benign Epilepsy with Centrotemporal Spike," Front Neurol, vol. 12, pp. 668- 856 ,2021.

[11] J. Royer, S. Bernhardt, E. Bc, Larivie`re, Gleichgerrcht, S. Vorderwu¨lbecke, Bj, and Vullie´moz, "Epilepsy and brain network hubs," Epilepsia, vol. 63, pp. 537–550, 2022.

[12] M. Centeno and D. W. Carmichael, "Network Connectivity in Epilepsy: Resting State fMRI and EEG-fMRI Contributions," Front Neurol, vol. 5, pp. 93–93, 2014.

[13] Nieto-Castanon, A. (2020b). 'FMRI minimal preprocessing pipeline'. Handbook of functional connectivity Magnetic Resonance Imaging methods in CONN, pages 3–16.

[14] R. S. Desikan, F. Se´gonne, B. Fischl, B. T. Quinn, B. C. Dickerson, D. Blacker, R. L. Buckner, A. M. Dale, R. P. Maguire, B. T. Hyman, M. S. Albert, and R. J. Killiany, "' An automated labeling system for subdividing the human cerebral cortex on MRI scans into gyral based regions of interest," Neuroimage, vol. 31, no. 3, pp. 968–980, 2006.

[15] V. D. Calhoun, T. D. Wager, A. Krishnan, K. S. Rosch, K. E. Seymour, M. B. Nebel, S. H. Mostofsky, S. H. Nyalakanai, P. Kiehl, and K, "The impact of T1 versus EPI spatial normalization templates for fMRI data anal yses," Hum Brain Mapp, vol. 38, no. 11, pp. 5331–5342, 2017.

[16] Nieto-Castanon, A. (2020c). 'FMRI minimal preprocessing pipeline'. Handbook of functional connectivity Magnetic Resonance Imaging methods in CONN, pages 26-62

[17] Nieto-Castanon, A. (2020d). 'General Linear Model'. Handbook of functional connectivity Magnetic Resonance Imaging methods in CONN, pages 63–82.

[18] Nieto-Castanon, A. (2020a). 'Cluster-level inferences'. Handbook of functional connectivity Magnetic Resonance Imaging methods in CONN, pages 83–104

[19] Y. Benjamini and Y. Hochberg, "'Controlling the false discovery rate: a practical and powerful approach to multiple testing," Journal of the Royal Statistical Society: series B (Methodological), vol. 57, no. 1, pp. 289–300, 1995.

[20] Z. Haneef, A. Lenartowicz, H. J. Yeh, H. S. Levin, J. E. Jr, and J. M. Stern, "JM. 'Functional connectivity of hippocampal networks in temporal lobe epilepsy," Epilepsia, vol. 55, no. 1, pp. 137–182, 2014.

[21] F. R. Pereira, A. Alessio, and M. S. Sercheli, "'Asymmetrical hippocampal connectivity in mesial temporal lobe epilepsy: evidence from resting state fMRI," BMC Neuroscience, vol. 11, pp. 66–66, 2010.

[22] X. Zhao, Z. Q. Zhou, Y. Xiong, X. Chen, K. Xu, J. Li, Y. Hu, X. L. Peng, and W. Z. Zhu, "Interhemispheric White Matter Asymmetries in Medial Temporal Lobe Epilepsy With Hippocampal Sclerosis," Frontiers in Neurology, vol. 10, pp. 394–394, 2019.

[23] C. Pressl, P. Brandner, S. Schaffelhofer, K. Black- mon, P. Dugan, M. Holmes, T. Thesen, R. Kuzniecky, O. Devinsky, and W. A. Freiwald, "Resting-state functional connectivity patterns associated with pharmaco- logical treatment resistance in temporal lobe epilepsy," Epilepsy Research, 2019.

[24] M. Fleury, S. Buck, L. P. Binding, L. Caciagli, S. B. Vos, G. P. Winston, P. J. Thompson, M. J. Koepp, J. S. Duncan, and M. K. Sidhu, "'Episodic memory network connectivity in temporal lobe epilepsy," Epilepsia, vol. 63, no. 10, pp. 2597–2622, 2022.

[25] A. J. Barnett, V. Man, and M. P. Mcandrews, "Parcellation of the Hippocampus Using Resting Functional Connectivity in Temporal Lobe Epilepsy," Frontiers in Neurology, 2019.

# Blockchain-based Teaching Evaluation System for Ensuring Data Integrity and Anonymity

Md. Mijanur Rahman, Uttam Kumar Saha, Shohedul Islam, Sanjida Akhter

Department of Computer Science and Engineering, Southeast University, Dhaka, Bangladesh

*Abstract*—The significance of student feedback within educational institutions cannot be overstated, as it serves as a pivotal tool for evaluating faculty performance and identifying potential gaps in course content. Blockchain technology has emerged as an increasingly promising solution for diverse digital applications, owing to its distinctive attributes and robust security features. This study endeavors to explore the use of blockchain technology for secure student feedback systems in education, specifically for analyzing faculty performance in a course. However, a noteworthy challenge that plagues existing feedback systems is their inability to ensure complete anonymity, leading to students' hesitancy in providing candid and honest feedback. Furthermore, these conventional systems often rely on databases for data storage, rendering them susceptible to tampering and data breaches. In response to these pressing concerns, the present paper proffers a comprehensive and innovative solution. The crux of the proposed approach revolves around the implementation of a blockchain-based student feedback system, artfully designed to guarantee both student anonymity and tamper-proof data storage, thereby facilitating the evaluation of teaching effectiveness. By leveraging the potential of an Ethereum-based blockchain, a secure and trusted platform is meticulously established, catering to the sensitive realm of student feedback in an impervious and confidential manner. Concomitantly, a user-friendly web application is deftly developed to complement the proposed system, meticulously documenting the implementation process, Smart Contract and project code. It is noteworthy that this cutting-edge feedback system provides an invaluable layer of security, fostering heightened user trust and engendering an environment conducive to genuine and authentic evaluations.

*Keywords—Blockchain; student feedback system; faculty performance evaluation; anonymity; smart contract, ethereum*

## I. INTRODUCTION

In today's educational landscape, student feedback is a vital component for organizations seeking to analyze and address various issues. This invaluable information is utilized to make important decisions within the organization, assess faculty performance in specific courses, identify solutions for existing problems, as well as inform future improvements. As such, feedback is treated with utmost care and consideration. Feedback plays a crucial role in assessing student achievement, promoting skill development, enhancing understanding, and fostering student motivation and confidence [1]. There is an ever-growing need to measure the activities and performance of faculty members in colleges and universities. Evaluating faculty performance is one of the most critical tasks within an institution and it has become a top priority worldwide [2]. However, most organizations rely on databases to manage their feedback systems. Therefore, the system administrator holds the authority to remove, alter, and manipulate the given feedback [3]. Henceforth, it is evident that the feedback system within the database management system does not provide anonymity [4]. According to a report published in [5], A $2.2 million fine was imposed on an Australian hotel business for deleting negative reviews from their website. A blockchain system that is decentralized, immutable, and auditable is inherently suited to prevent fraudulent and manipulated reviews [6].

Blockchain ushers in a new era of innovation and represents a huge advancement in decentralized information technology [7]. It offers several benefits to the education evaluation process, including decentralization, classification, and secure storage of evaluation data. By leveraging blockchain's inherent security features, such as immutability and tamper-resistance, it can enhance the confidentiality of data and prevent unauthorized access or modification [8]. The faculty members who receive or view feedback may be negatively impacted by the organization and their students if negative feedback is disclosed. Furthermore, faculty members may attempt to uncover the identity of students who have given negative feedback through administrators or databases, which could lead to adverse effects on those students. Administrators with access to databases can also change feedback or reveal the identities of the students who submitted it, thereby this feedback system does not remain fully anonymous. Maintaining confidentiality and safeguarding anonymity are fundamental components of an effective feedback system. Utilizing blockchain technology and its numerous fascinating characteristics, including anonymity, validation, robustness, and potential integration, one can create a feedback system that preserves anonymity effectively [9].

Satoshi Nakamoto introduced the concept of blockchain technology in 2008 by publishing a paper on Bitcoin [10] [11]. Blockchain is a decentralized ledger system that utilizes a network of distributed nodes to create a highly trustworthy ledger system without relying on third-party verifiers. The distinctive structure of the blockchain is data protection, anonymity, transparency, and integrity [12]. Blockchain technology aims to achieve a decentralized consensus among network nodes, where data is distributed and no single node has complete control [13]. It is a decentralized database that stores records in blocks [14]. Every block includes a hash value, timestamp, and the transaction's details. A hash function is employed to transform a collection of data into a compact and fixed-sized data structure referred to as a hash value [15] [16].

We looked over some of the research papers on feedback systems based on blockchain and tried to investigate the gaps. We found some research papers related to feedback systems that showed an opportunity to alleviate the existing challenges in this field. The existing Ethereum blockchain-based feedback system doesn't use any encryption and decryption process while login/registration and storing passwords on the blockchain. But in this paper user password encryption and decryption during login, registering, and storing on the blockchain is done using bcrypt algorithm.

Therefore, we proposed a secure student feedback system for the evaluation of faculty performance using blockchain technology, designed to prioritize user anonymity and tamper-proof features. With this system, data remains unaltered and secure, preventing both administrators and faculty members from accessing the identities of students who submitted feedback. Consequently, this system delivers enhanced security and anonymity, empowering students to provide feedback with confidence.

The subsequent parts of the paper are organized in the following manner. A synopsis of the prior related literature is given in Section II. Section III presents the methodology and implementation of the proposed blockchain-based teaching evaluation system. Section IV describes the results and Section V delves into discussion. Lastly, the paper's conclusion is presented in Section VI.

## II. LITERATURE REVIEW

The existence of blockchain predates its introduction by Satoshi Nakamoto with the advent of Bitcoin [17] [18]. Its influence has been profound and all-encompassing, witnessing widespread adoption across various industries and sectors, driven by its potential to enhance security, efficiency, and transparency. In recent times, blockchain technology has emerged as a frontrunner in the realm of innovation, garnering substantial attention from the global public and academic communities [19]. Blockchain technology attained remarkable prominence, establishing itself as a leading technological breakthrough on a global scale. Consequently, an array of comprehensive research endeavors have been undertaken to delve into the intricacies of this system, culminating in proposed advancements and revisions to existing studies. This surge in interest underscores the profound significance of blockchain technology as an enabler of progressive and transformative solutions across various domains.

In their seminal work, Zheng et al. provided invaluable insights into the architecture of blockchain technology, shedding light on the intricate algorithms that underpin consensus among its participants. The authors also dedicated attention to the technology's inherent limitations, offering innovative solutions to mitigate these challenges. Their rigorous analysis encompasses a comparative evaluation of diverse consensus algorithms, with the overarching goal of identifying the most fitting approach for a multitude of applications [20].

Rahman et al. introduced a pioneering blockchain-based feedback system, meticulously engineered to safeguard user anonymity. The primary objective of this system is to empower users to provide feedback without compromising their privacy. Notably, once feedback is submitted, it becomes immutable. Furthermore, the system meticulously safeguards the privilege of providing feedback for registered users. However, the cloak of anonymity raises the potential for intentional negative feedback to tarnish the reputation of recipients [21].

Chandratre et al. proposed an innovative blockchain-based course feedback system, harnessing the power of Ethereum blockchain for its development. This inventive system integrates a survey management component, enhancing longevity and traceability. The feedback process unfolds through well-defined phases: initiation commences with the administrator crafting a survey form, followed by students sharing their feedback, culminating in the secure storage of this feedback on the blockchain [22].

Salah et al. demonstrated an online review system rooted in blockchain technology, featuring the use of the Solidity programming language and the Remix Integrated Development Environment (IDE) for implementation and testing. The system not only rewards genuine reviewers with tokens and Ether-based compensation for their reviews but also securely archives verified reviews within the InterPlanetary File System (IPFS), thereby ensuring their integrity and reliability. In a forward-looking approach, the authors aspire to develop user-friendly decentralized applications to further facilitate the work of reviewers [23].

Karode et al. presented an innovative blockchain-based online review system aimed at enhancing transparency on business platforms by combatting the prevalence of fake or unreliable reviews. Leveraging the Ethereum blockchain, this system securely stores review data, effectively thwarting data manipulation. Additionally, it ensures the public traceability of actions, significantly elevating the transparency of the online review system through the integration of blockchain technology. However, it's important to note that the adoption of blockchain in this context may introduce challenges, including increased costs and potentially slower response times [24].

The research papers previously mentioned delve into the development of student feedback systems that prioritize anonymity and data integrity. However, our innovative approach takes a step further, encompassing a performance-based evaluation system that serves both as a feedback mechanism and a valuable resource for identifying effective solutions to similar challenges. Diverging from some existing feedback systems, where administrators assign students to specific courses eligible for feedback, our proposed system introduces a seamless and automated validation process. By offering students the opportunity for self-registration, they gain access to provide feedback exclusively for the courses in which they are enrolled. Moreover, we introduce a rating-based system for evaluating faculty performance, a salient feature that bears immense potential for driving organizational improvement.

## III. METHODOLOGY

The principal aim of our system revolves around the seamless facilitation of anonymous feedback while upholding the inviolable integrity of data, thereby empowering students to

express candid opinions without hesitation. To achieve this pivotal objective, we judiciously harnessed the potential of blockchain technology, renowned for its remarkable capacity in safeguarding anonymity and preserving the unassailable authenticity of submitted feedback. Our system, thoughtfully designed, imposes stringent measures to guarantee that solely registered users possess the privilege to proffer feedback, assiduously safeguarding the covert identities of students, and diligently ascertaining that the feedback reaches its intended recipient for meticulous review. Fig. 1 below illustrates the system architecture of our proposed system.
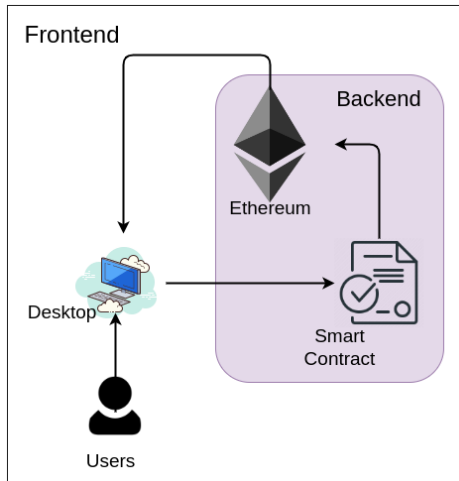


Fig. 1. System architecture.

As depicted in Fig. 1, our system has two distinct parts: front-end and back-end. The front-end is built using React.js and the back-end is developed using the Ethereum blockchain.

Our system involves three key actors: the administrator, faculties, and students, each with a unique set of functionality that will be performed from their particular dashboard. To ensure anonymity, students provide feedback through customized forms accessible from the front-end of the system. This feedback is processed through smart contract and securely stored on the Ethereum blockchain. The administrator and faculties can easily access this feedback through their respective dashboards, which retrieve the data directly from the blockchain.

The student feedback system's diagram is clearly illustrated in Fig. 2 below, which depicts the various actors and their functionality and how the system is working. To initiate their engagement with the system, users are required to establish a connection to their Metamask wallet, followed by a secure login procedure employing a unique username and password. Once the username and password are validated, the system will identify the user's role, which may be administrator, faculty, or student. Depending on their role, users will be redirected to their corresponding dashboard, where they can perform specific functions tailored to their needs. The administrator can use the dashboard to manage user accounts, including registering new faculty and student accounts, creating new courses, and viewing all student feedback. Students, on the other hand, can use their dashboard to get enrolled in courses, and write and send feedback to specific faculty members and courses. Students are only able to submit feedback once in a course and cannot modify their responses afterward. Finally, faculties can access and view all feedback directed to them via their dashboard.
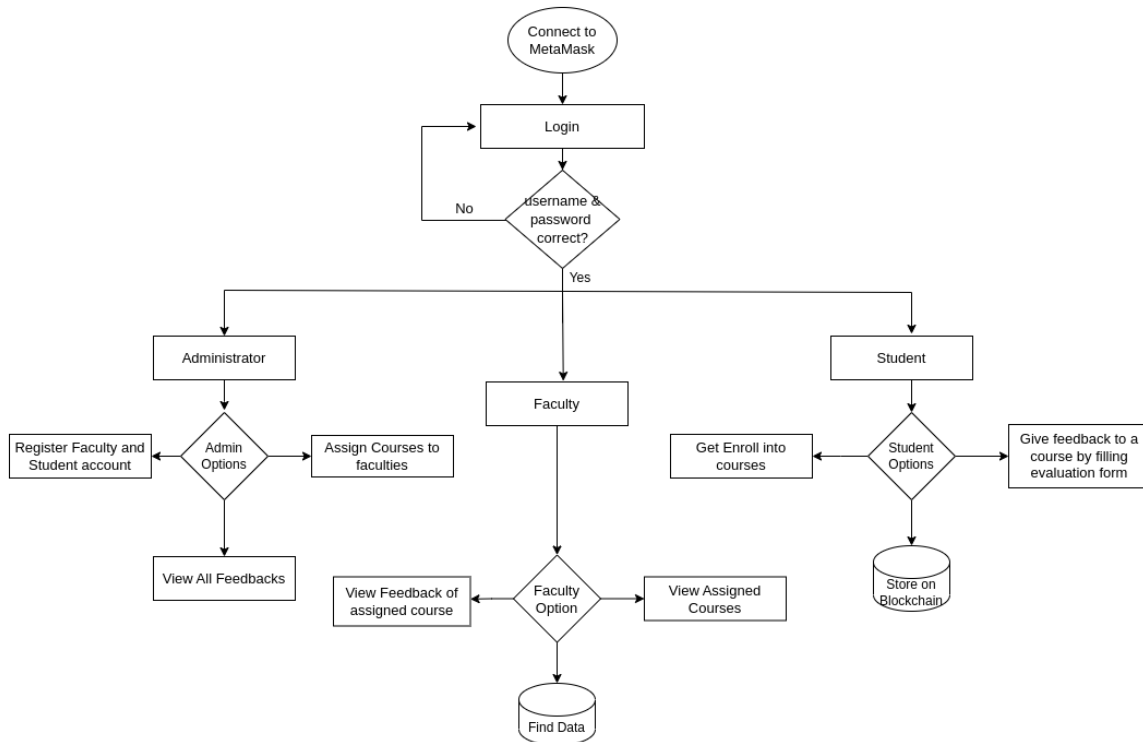


Fig. 2. Diagram of the proposed system.

## A. Working Procedure

We have developed a student feedback web application using blockchain technology. The whole procedure is divided into five phases described below.

*1) Registration phase:* In this phase, the administrator registers new student and faculty accounts by accessing create account option from the dashboard. Once created, these accounts can be used by students and faculties to log in to the system. The user password will be encrypted and stored on the blockchain. Also, the administrator will register all courses offered by the institution. The students can enroll in these courses later, and validation is done during the registration of user accounts and courses.

*2) Login phase:* Our web application begins with a login page where users are required to connect their Metamask wallet and enter their usernames and passwords. The system verifies the password against the encrypted hash stored in the blockchain. If the password matches, users gain access to their accounts and are redirected to their respective dashboards based on their roles (administrator, faculty, or student).

*3) Course enrollment phase:* During this phase, students will self-register for courses by accessing the enrollment option on their dashboard. They can view the institution's course list and enroll in a specific course by clicking on it.



Fig. 3. Student feedback form.

*4) Submit feedback phase:* During this phase, students will provide feedback on courses and instructors by accessing the give feedback option on their dashboard. They select the course and faculty member for evaluation and fill out a

feedback form with questions about the course and instructor. Our application's feedback evaluation form is illustrated in Fig. 3. The evaluation form consists of ten questions collected from the teaching evaluation system of Southeast University, Bangladesh. These questions help to evaluate the performance of the faculty. Each question carries a weight between 1 and 5 using a Likert scale from 1 (strongly disagree) to 5 (strongly agree). We have calculated an average rating point out of 10 from the Likert scale responses submitted by students to assess the faculty's performance. Students are also encouraged to provide comments along with their chosen rating.

*5) View feedback phase:* In this phase, both the administrator and faculty members can access student feedback through their respective dashboards. Administrators have access to all course feedback, while faculty members can only view feedback for their assigned courses. Fig. 4 below shows the feedback page, displaying student ratings and comments. Moreover, we have created a formula to assess faculty performance in each course on a scale of 0 to 100 percent. The formula is the sum of total ratings divided by the number of feedback submissions, then multiplied by 10. Every faculty member will see a performance rating against a course here which is measured by the above formula.
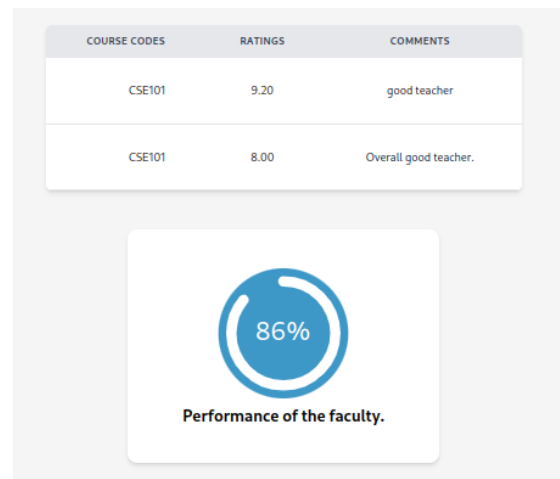


Fig. 4. View feedback page.

## B. Implementation

This section focused on the implementation of the project code. We described the pseudocodes of functions and the tools used to build the project.

---

**PSEUDO CODE 1**: Function to create new user account

```
1: function createUserAccount(username, password, role):
2:     if the caller is the contract owner then
3:             Create → new user account property
4:             Store ← new user account information
5:     else
6:             return "Caller is not the contract owner"
7:     end if
8: end function
```

---

The "createUserAccount()" function serves as a pivotal feature, granting administrative personnel the authority to

create new student and faculty accounts within the system. This function receives username, password, and role as parameters and is triggered when the administrator creates a student and faculty account from the client side.

---

**PSEUDO CODE 2:** Function to submit feedback

---

1:function submitFeedback( userAddress, courseCode, rating, comment):
2:     if the user has already submitted feedback then
3:          return "Your feedback already exists"
4:     else
5:          Create → a new feedback object
6:          Store ← the feedback
7:          Update → feedback track
8:     end if
9: end function

---

submitFeedback() function allows the student to give feedback or do an evaluation against a course. The function validates that a student can submit feedback into a course for once.

---

**PSEUDO CODE 3:** Function to view feedback

---

1: function getFeedback( courseCode ):
2:     return a list of feedback for the specified course code.
3: end function

---

getFeedback() function returns all feedback stored into the blockchain. This function allows the administrator and faculties to view feedback given by the students.

*C. Used Tools*

We utilized a variety of tools to effectively achieve the project objectives and outlined the specific tools used in this project below:

*1) Ethereum blockchain:* Ethereum is a blockchain platform that has its own digital currency known as Ether (ETH)[25]. Vitalik Buterin created it in 2014 [26]. It supports the development and deployment of decentralized applications. It is not controlled by any central authority [27].

*2) Solidity:* It is a powerful, user-friendly, and object-oriented language used to write smart contracts that operate on the Ethereum Virtual Machine.

*3) MetaMask:* It links users to the Ethereum blockchain and allows them to use the Ethereum wallet through a browser extension or mobile app. This allows them to interact effortlessly with decentralized or web3 applications [28].

*4) Remix:* Remix is an open-source online Ethereum IDE. It is the smartest way to write contracts using the Remix IDE[29]. We can use it to write, compile and debug code. We wrote and deployed smart contracts from here.

*5) ReactJS:* It is a JavaScript library created specifically for constructing dynamic and interactive user interfaces using a component-based approach [30]. It is used to develop front-end of our web application.

## IV. RESULTS

We conducted a survey involving a limited number of students to explore their perceptions of the traditional teaching evaluation system. Our findings revealed that a significant portion of the students expressed apprehension about providing honest feedback due to concerns about their anonymity being compromised. They believe that the conventional database-driven feedback system falls short of providing complete anonymity. Subsequently, we introduced our Blockchain-based teaching evaluation system, which garnered significant interest among the student participants. A number of students chose to utilize our system and reported high levels of satisfaction, citing its ability to ensure absolute anonymity.

For the development and experimental validation of our proposed system, the Remix Integrated Development Environment (IDE) serves as the primary tool for composing and assessing the smart contract. Subsequently, to facilitate thorough testing procedures, the smart contract is deployed onto the Remix virtual network, effectively replicating a decentralized environment for examination. Within the context of our smart contract design, a singular entity, known as the "smart contract deployer," assumes the authoritative role of the system's administrator.

Once the smart contract passed the testing phase, we proceeded to deploy it on the Goerli test network. Metamask wallet wanted confirmation during deployment. Upon successful deployment of our smart contract, the contract was created and its address was returned to the Remix IDE. We collected this smart contract address and ABI( Application Binary Interface) from Remix IDE. This contract address and ABI were used to make communication between front-end and blockchain. Our newly deployed smart contract address is 0x6F04207829759752079DEE48136fd447c3F6198f. The source code of our feedback system is made accessible through the following link: https://github.com/uttamsaha/Web3-Student-Feedback-System
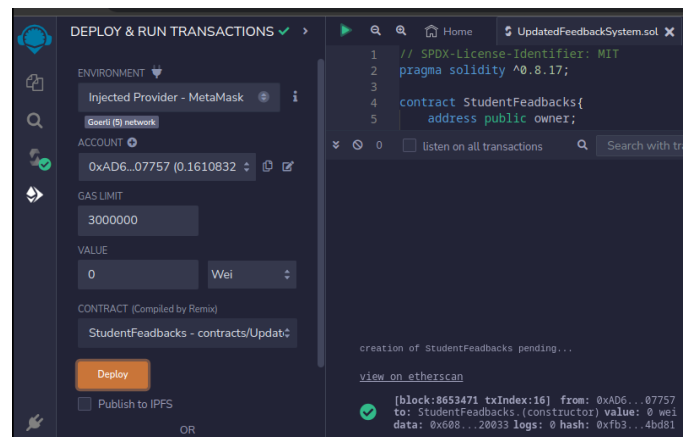


Fig. 5.    Deploy smart contract to Goerlitestnet.

Fig. 5 shows that we deployed our smart contract on the Goerlitestnet network.

## V. DISCUSSIOIN

We have conducted a comprehensive comparison between our newly implemented teaching evaluation system and the existing blockchain-based system, presenting our key findings. The existing system in [22] allows students to give feedback only but the proposed system allows evaluating the

performance of a faculty in a course along with giving feedback. This existing system is quite manual for generating a permission list that maintains who can give feedback in a course, but it was maintained automatically in this work. Instead of knowing all usernames and passwords, the administrator or someone else cannot perform any action or view on student and faculty accounts because we developed and mapped the user information using their Metamask wallet address. This enhances the overall security measures. The traditional and existing system does not give such features

In our system, we implemented a robust encryption mechanism to safeguard user passwords during storage within the blockchain. Subsequently, when the user's login function is called, the stored password is decrypted securely. This encryption-decryption process serves as an integral aspect of our security infrastructure, augmenting the overall protection of user credentials and sensitive data. Furthermore, we devised a comprehensive performance evaluation approach for faculty members, quantifying their performance in courses through a percentage-based assessment. This helped the authority to know how a faculty is performing in the class. To uphold the integrity of the feedback process, we meticulously designed the system to ensure that each student is limited to providing feedback to a faculty member once and also ensured students can get enrolled in a course once.

## VI. CONCLUSION

In today's digital age, feedback stands as a critical element for organizational enhancement and progress. Nonetheless, parallel to the imperative of obtaining valuable feedback is the need to safeguard the security and anonymity of the contributors. Preserving confidentiality emerges as a substantial challenge for any feedback system, as participants might harbor apprehensions about potential identity exposure. Consequently, feedback systems necessitate meticulously crafted designs that incorporate advanced security measures, effectively addressing these concerns and ensuring robust privacy and confidentiality. The challenges of ensuring confidentiality and security in feedback systems find a compelling resolution through the adoption of blockchain technology. Its inherent attributes, including decentralization, tamper-proofing, enhanced security, and anonymity, make it an ideal fit for addressing these concerns. Recognizing the potential of blockchain, our organization has harnessed its capabilities to construct a cutting-edge student feedback system that prioritizes both anonymity and security for its users. By leveraging blockchain, our system empowers users to freely and honestly express their feedback without the fear of their identity being exposed or facing repercussions. That is how our feedback system becomes more effective, reliable, trustworthy, and secure.

The feedback system does not permit modifications. Consequently, if a student inadvertently submits an incorrect evaluation, there is no opportunity to revise it. In our system, where user anonymity is maintained, someone may purposefully provide negative feedback with the intention of harming a candidate's reputation. As the system will rely on blockchain technology for maintenance, the transaction rate is expected to be relatively slow.

The knowledge we've gained through this experience can be applied to other feedback systems or adapted for different applications in the future. Companies that rely on rating mechanisms can seamlessly integrate our feedback system into their operational framework, leveraging its robust features to enhance their feedback collection and analysis processes. Also, this system can be used to develop a survey management and evaluation system using blockchain.

## REFERENCES

[1] T. Hatziapostolou and I. Paraskakis, "Enhancing the Impact of Formative Feedback on Student Learning Through an Online Feedback System," vol. 8, no. 2, pp. 111–122, 2010.

[2] S. Bai, Q. Rajput, S. Hussain, and S. A. Khoja, "Faculty performance evaluation system: An ontological approach," Proc. IEEE/ACS Int. Conf. Comput. Syst. Appl. AICCSA, vol. 2014, no. September 2015, pp. 117–124, 2014, doi: 10.1109/AICCSA.2014.7073187.

[3] M. Shaker, F. Shams Aliee, and R. Fotohi, "Online rating system development using blockchain-based distributed ledger technology," Wirel. Networks, vol. 27, no. 3, pp. 1715–1737, 2021, doi: 10.1007/s11276-020-02514-w.

[4] Chandra and Billy " Teaching feedback using blockchain and blind signature", Nanyang Technological University, SCSE19-0196, 2020.

[5] D. Williams, "Australian hotel chain fined $2.2 million for manipulating TripAdvisor reviews." cnn.com. https://edition.cnn.com/travel/article/australia-tripadvisor-hotel-fined-trnd/index.html (Accessed: 18 Apr 2023).

[6] K. Wang, Z. Zhang, and H. S. Kim, "ReviewChain: Smart Contract Based Review System with Multi-Blockchain Gateway," Proc. - IEEE 2018 Int. Congr. Cybermatics 2018 IEEE Conf. Internet Things, Green Comput. Commun. Cyber, Phys. Soc. Comput. Smart Data, Blockchain, Comput. Inf. Technol. iThings/GreenCom/CPSCom/SmartData/Blockchain/CIT 2018, pp. 1521–1526, 2018, doi: 10.1109/Cybermatics_2018.2018.00256.

[7] Q. Feng, D. He, S. Zeadally, M. K. Khan, and N. Kumar, "A Survey on Privacy Protection in Blockchain AC," J. Netw. Comput. Appl., 2018, doi: 10.1016/j.jnca.2018.10.020.

[8] S. Ouyang and X. Huang, "Education Evaluation Management Based on Blockchain Technology," Mob. Inf. Syst., vol. 2022, 2022, doi: 10.1155/2022/7513365.

[9] M. M. Rahman, M. S. Uddin Siddiqe, and A. Uddin, "Headhunting System Using Blockchain Technology," in HORA 2022 - 4th International Congress on Human-Computer Interaction, Optimization and Robotic Applications, Proceedings, 2022. doi: 10.1109/HORA55278.2022.9799851.

[10] X. Wang, L. Feng, H. Zhang, C. Lyu, L. Wang, and Y. You, "Human Resource Information Management Model based on Blockchain Technology," Proc. - 11th IEEE Int. Symp. Serv. Syst. Eng. SOSE 2017, pp. 168–173, 2017, doi: 10.1109/SOSE.2017.34.

[11] M. Rahman, M. Azam, and F. S. Chowdhury, "Secure Complaint Management System against Women Harassment at Workplace Using Blockchain Technology," Int. J. Electr. Comput. Eng. Syst., vol. 13, no. 3, pp. 209–217, 2022, doi: 10.32985/IJECES.13.3.6.

[12] J. Yli-Huumo, D. Ko, S. Choi, S. Park, and K. Smolander, "Where is current research on Blockchain technology? - A systematic review," PLoS One, vol. 11, no. 10, pp. 1–27, 2016, doi: 10.1371/journal.pone.0163477.

[13] N. O. Nawari and S. Ravindran, "Blockchain and the built environment : Potentials and limitations," vol. 25, no. October 2018, 2019, doi: 10.1016/j.jobe.2019.100832.

[14] A. B. Ayed, "A CONCEPTUAL SECURE BLOCKCHAIN - BASED ELECTRONIC VOTING SYSTEM," no. May, 2020, doi: 10.5121/ijnsa.2017.9301.

[15] M. M. Rahman, M. T. K. Tonmoy, S. R. Shihab, and R. Farhana, "Blockchain-based certificate authentication system with enabling correction," 2023, [Online]. Available: http://arxiv.org/abs/2302.03877.

[16] F. Mollik, M. Rahman, M. Hasan, and M. Akter, "Blockchain in Human Resource Management System" no. February, 2023, doi: 10.13140/RG.2.2.34817.53609.

[17] S. Nakamoto, "Bitcoin: A peer-to-peer electronic cash system," Decentralized business review, p. 21260, 2008.

[18] S. Haber and W. S. Stornetta, "How to time-stamp a digital document," J. Cryptol., vol. 3, no. 2, pp. 99–111, 1991, doi: 10.1007/BF00196791.

[19] N. R. Al Hamrani and A. R. Al Hamrani, "People of Determination (Disabilities) Recruitment Model Based on Blockchain and Smart Contract Technology," Technol. Invest., vol. 12, no. 03, pp. 136–150, 2021, doi: 10.4236/ti.2021.123008.

[20] Z. Zheng, S. Xie, H. Dai, X. Chen, and H. Wang, "An Overview of Blockchain Technology: Architecture, Consensus, and Future Trends," Proc. - 2017 IEEE 6th Int. Congr. Big Data, BigData Congr. 2017, pp. 557–564, 2017, doi: 10.1109/BigDataCongress.2017.85.

[21] M. M. Rahman, M. M. H. Rifat, M. Y. Tanin, and N. Hossain, "A feedback system using blockchain technology," Proc. 3rd Int. Conf. Intell. Sustain. Syst. ICISS 2020, pp. 1114–1118, 2020, doi: 10.1109/ICISS49785.2020.9315989.

[22] A. Chandratre and S. Garg, "Blockchain Based Course Feedback System," SSRN Electron. J., 2021, doi: 10.2139/ssrn.3762332.

[23] K. Salah, A. Alfalasi, and M. Alfalasi, "A Blockchain-based System for Online Consumer Reviews," INFOCOM 2019 - IEEE Conf. Comput.

[24] Commun. Work. INFOCOM WKSHPS 2019, pp. 853–858, 2019, doi: 10.1109/INFOCOMW.2019.8845186.

[24] T. Karode and W. Werapun, "Performance Analysis of Trustworthy Online Review System using Blockchain," 17th Int. Conf. Electr. Eng. Comput. Telecommun. Inf. Technol. ECTI-CON 2020, pp. 510–513, 2020, doi: 10.1109/ECTI-CON49241.2020.9158212.

[25] J. Frankenfield, "What Is Ethereum and How Does It Work?." investopedia.com. https://www.investopedia.com/terms/e/ethereum.asp (accessed Apr. 12, 2023).

[26] D. Martens and W. Maalej, "ReviewChain: Untampered product reviews on the blockchain," Proc. - Int. Conf. Softw. Eng., pp. 40–43, 2018, doi: 10.1145/3194113.3194120.

[27] K. Kelley, "What is Ethereum? Explained With Features and Applications." simplilearn.com. https://www.simplilearn.com/tutorials/blockchain-tutorial/what-is-ethereum (accessed Feb. 17, 2023).

[28] D. Pramulia, "Implementation and evaluation of blockchain based e-voting system with Ethereum and Metamask," pp. 18–23, 2021.

[29] R. M. A. Latif, K. Hussain, N. Z. Jhanjhi, and A. Nayyar, "A remix IDE : smart contract-based framework for the healthcare sector by using Blockchain technology," 2020.

[30] S. Aggarwal, "Modern Web-Development using ReactJS," vol. 5, no. 1, pp. 133–137, 2018.

# Dynamic Routing Using Petal Ant Colony Optimization for Mobile Ad-hoc Networks

Sathyaprakash B.P[1], Manjunath Kotari[2]

School of Electronics and Communication Engineering, REVA University, Bengaluru-560064, India[1]
Research Scholar, Visvesvaraya Technological University, Belagavi-590018, India[1]
Dept. of CSE, Alva's Institute of Engineering and Technology, Moodbidri, Mangalore-574225, India[2]
Visvesveraya Technological University, Belagavi-590018, India[2]

*Abstract*—A Mobile Ad-hoc Network (MANET) is a temporary wireless network that configures itself as needed. Each MANET node has a finite number of resources and serves as both a node and a router at the same time. MANET nodes are mobile and move from one location to another. Because MANET nodes are dynamic, choosing an optimal node for data transfer is a difficult issue. Because packets must propagate in a multi-hop manner, they take a longer path and may endure a longer delay, causing them to become lost in the network. The network's overall performance suffers as a result of the re-transmission of those lost packets. We propose a modified version of a nature-inspired algorithm called Petal Ant based Dynamic Routing (PADR) in this research study, which reconstructs data packets to traverse inside a given region and achieves minimal delay during data transmission. The PADR is simulated in Network Simulator (NS2) and compared against nature-inspired routing protocols like PAR and SARA, as well as traditional routing protocols like AODV.

*Keywords*—*Petal ant routing; dynamic petal ant routing; MANET; ant colony optimization*

## I. INTRODUCTION

In our day-to-day lives, wireless communication networks are becoming increasingly crucial [3] [12]. Wireless devices connect, exchange, and transfer data wirelessly, giving them a substantial level of mobility [20]. Infrastructure-based networks and infrastructure-less networks are the two types of wireless networks available [1] [19]. Wireless devices communicate in infrastructure-based networks through a centralized administration, such as a base station or an access point [28]. The wireless device communicates directly with no pre-existing communication infrastructure in an infrastructure-less network, which is known as an Ad-hoc Network. Mobile Ad-hoc Network is an example of an ad-hoc network (MANET) [5].

The Mobile Ad-hoc Network is a transitory wireless network made up of a collection of wireless devices such as laptops, PDAs, and mobile phones that may dynamically configure, communicate, and react with no central administration [6][7]. Because MANET's nodes are mobile, they connect to other networks using a regular Wi-Fi connection [23]. Because MANET mobile nodes communicate with one another over a wireless medium, the devices must establish a communication link and send data to others even when they are not in direct transmission range [14][30]. MANETs, in general, forward data in a multi-hop fashion and

serve as routers even when no infrastructure equipment is present [16][31]. Congestion, routing, security, and other challenges arise as a result of a MANET's absence of infrastructure equipment [18] [29]. One of the most important challenges is routing, because when determining the best way for data transmission, complications like delay, performance, throughput, and overheads can generate a slew of problems and reduce network efficiency [4] [15]. As a result, additional strategies are required to overcome such difficulties with high node mobility, according to [25] [17]. A Routing in a MANET is a common theme that has resulted in numerous routing protocols in the literature and has remained a difficult issue for the past few decades [21] [22].

The key contributions and originality aspects of the proposed routing are as follows:

*1) To* identify the shortfalls of existing PAR route discovery procedure. We provide a cutting-edge technique for obtaining petal width from static to dynamic petal between end nodes.

*2) Our* approach aims to maximize the data delivery rate between end-to-end nodes during data transmission by discriminating the mobile node during the process. We propose an innovative technique of electing the nearest neighboring node so that delay and routing overheads between end nodes is minimum as quoted in the algorithm. This impacts the performance and user experience of various applications and services in the real world.

*3) For* each of the proposed tests, 20 simulation runs were conducted ranging from 15 to 150 mobile nodes, and an average value was calculated at the end of the simulation. The suggested routing algorithm is evaluated for various metrics such as packet delivery fraction, throughput, overhead and delay, and the results are compared with PAR routing.

Overall, this article proposes an extension of the ant colony optimization technique, a nature-inspired algorithm that optimizes both the route discovery and route maintenance mechanisms for data delivery from groups of mobile nodes in MANETs. The proposed technique evaluation results demonstrate its effectiveness in discriminating node during route discovery and provides better performance than PAR routing strategy. The following section contains various related works, our contributions, and an analysis of the results.

## II. RELATED WORK

Hua Wang, Z ao Shi, et al. (2008) [2] proposed a modified Ant Colony algorithm for ad-hoc networks that included a progressive changing orientation component and used it to solve multi-constraint routing problems. The gradual changing orientation factor's directionality allows the ants to consider direction when searching for a path, allowing them to proceed fast to the end node and so improve convergence speed by overcoming the slow convergence setback. According to the author, an ant in the improved algorithm not only uses prior search findings, but also lowers the misguiding influence of pheromones on improper paths, overcoming the sluggish convergence problem. The results of the experiments show that the ant colony algorithm with progressive shifting orientation factor outperforms the standard ant colony algorithm in terms of convergence time while also avoiding the risk of a local best solution.

Saptarshi Benerjee et al., [9] (2015) suggested a new MANET routing strategy based on on-demand multipath power balanced routing. The routing protocol in [9] is a modified version of the ACO architecture, and it consists of three phases: Route Discovery, Route Maintenance, and Route Failure. The routing algorithm updates the pheromone value in the routing table using the battery charge of a mobile node as the major parameter. During the route discovery phase, the routing algorithm uses the identical Forward Ant (FANT) and Backward Ant (BANT) generated by the source and destination. The source establishes the communication channel to the destination based on the pheromone value obtained by the probability of battery charge of mobile nodes. In OMNET++ version 4.5, the routing algorithm is simulated for a small-scale network. The simulation findings show that the ACO algorithms give better packet delivery count convergence than the existing ACO algorithms.

B Jayalalitha et al., (2016) [11] For MANET, the ANT Colony Optimization Routing (ACOR) algorithm was presented as a variation of the ant routing technique. The ACOR is proactive routing, similar to AntHocNet, which sends out control packets regularly. The author of ACOR modified the Ant-route proto-header packet and successfully complied for execution, but the packets were not transmitted from source to destination node. In NS2, the ACOR is modeled and compared to AntHocNet, AODV, and DSR. According to ACOR, AntHocNet, AODV, and DSR simulation results, the ACOR builds the routing table but fails to transport packets between end nodes.

Ajay Kumar et al., (2017) [15] the importance of MANETs is discussed, as well as the disadvantages of routing for temporary networks. The author of [10] introduced the Efficient Fuzzy based Multi-constraint Multicast Routing protocol (EFM- MRP), which uses fuzzy logic to supervise uncertainty issues. The algorithm calculates the fuzzy cost and chooses the best path between end nodes with the lowest fuzzy cost, then sends the data to a group of receivers. In NS 2.35, the EFMMRP is simulated for 15 to 300 mobile nodes. For mobility, the EFMMRP employs the random waypoint network model, while the propagation model is based on the free space propagation model. The EFMMRP is compared to the On-demand Multicast Routing Protocol (ODMRP) and the Multicast Ad-hoc On-Demand Distance Vector Routing Protocol (MAODV). The simulation results of EFMMRP, ODMRP, and MAODV show that EFMMRP outperforms ODMRP and MAODV in terms of delay, bandwidth, and energy metrics when faced with uncertainty.

Dipika Sarkar et al. (2018) [20] proposed the Enhanced Ant-AODV routing protocol for MANET, which is based on Quality of Service (QOS). The Enhanced-Ant-AODV is a reactive technique for MANET route selection that combines AODV with ANT. In the frame format of the AODV route request and route reply packet, an extra field called Pheromone count has been added. Based on the pheromone value, hop count, congestion, and reliability of the path between the end nodes, the Enhanced-Ant-AODV chooses a finite route for data delivery. The path with the highest pheromone value is chosen as the optimum data delivery path. In NS 2.35, the Enhanced-Ant-AODV is simulated and tested with the AODV and DSR MANET routing protocols.

Valanto Alappatt et al. (2020) [18] to solve the issue of routing, the authors proposed Ant Colony Optimization and Binary Particle Swarm Optimization (ACO: BPSO), a modified version of the ant colony optimization technique for mobile ad hoc networks. The ACO: BPSO is a hybrid approach for enhancing the network's lifetime that combines Ant Colony Optimization and Binary Particle Swarm Optimization techniques. In NS2, the ACO: BPSO routing protocol is simulated for 50 nodes and compared to the regular AODV routing system. Based on the simulation results, the author of [18] claims that the ACO: BPSO hybrid strategy outperforms the AODV routing protocol in terms of packet delivery rate, throughput, and residual energy.

## III. PROPOSED ALGORITHM: PETAL ANT DYNAMIC ROUTING (PADR)

As described in several research proposals published in the literature, real ants are able to find the fastest and most efficient road to get from their food source to their nest in response to their environment [26] [13]. Petal Ant based Dynamic Routing (PADR) is a reactive routing system that is a variant of the Ant Colony Optimization (ACO) Algorithm. When a wireless node is out of transmission range, the PADR divides the network into a Petal Region ($P_w$), which makes it easier for the node to choose a destination from the source. The detailed description of the proposed algorithm is as follows:

The Petal Ant based Dynamic Routing (PADR) algorithm has three phases namely

- Route Discovery,
- Route Maintenance, and
- Route Repair

### A. Route Discovery

Consider the example of a small network of 10 nodes shown in Fig. 1. The wireless mobile nodes are represented by the alphabets A, B, C, D, E, F, G, H, and I, with the node S denoting the Source, D denoting the Destination, and the other nodes denoting the Intermediate node in the network. If any

source node seeks to construct a data path to a destination node during the route discovery phase, the PADR divides the network into petal regions ($P_w$). If S does not have a routing table entry for destination D in its routing table, node S divides the network into petal regions as illustrated in the Fig. 1 using equations (1, 2, 3), where ($x_s$ , $x_d$) and ($y_s$ , $y_d$) are the longitudes and latitudes in real-time measurements of node S and D, d is the distance of S & D, "c" is a variable (minor axis), "a" is 50% of d and "b" is 50% of c.
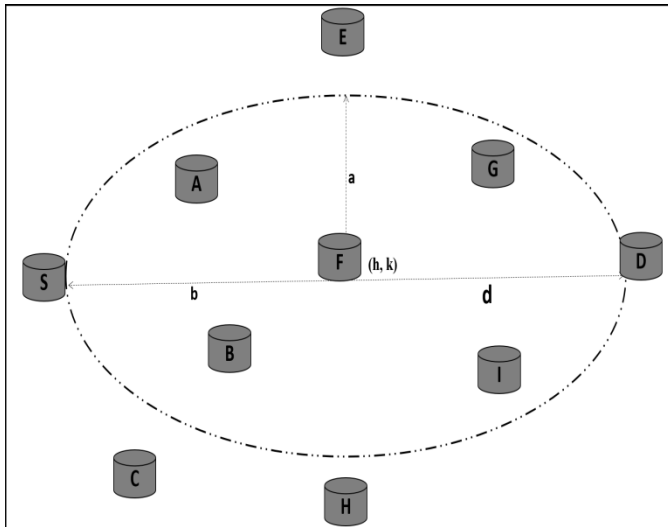


Fig. 1.    PAR - petal region calculation.

$$\sqrt{(x_d - x_s)^2 + (y_d - y_s)^2} \tag{1}$$

$$h = (x_{s+} x_d)/2 \,, \ k = (y_{s+} y_d)/2 \tag{2}$$

$$\mathrm{Pw} = \pi ab \tag{3}$$

Once the petal width between end nodes has been determined, the source propagates P_FANT across the network. The rebroadcasting of the P_FANT packet is delayed until it reaches D, which response with P_BANT as an acknowledgment to the P_FANT packet. The route discovery procedure of PADR is depicted in Fig. 2 and Fig. 3.
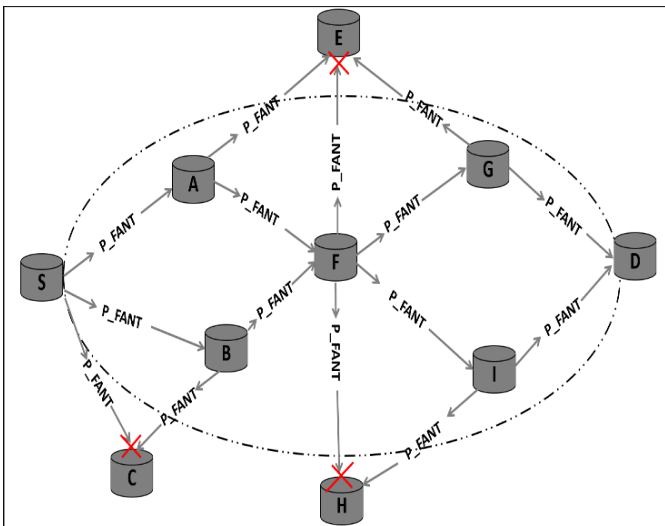


Fig. 2.    PADR – P_FANT propagation.
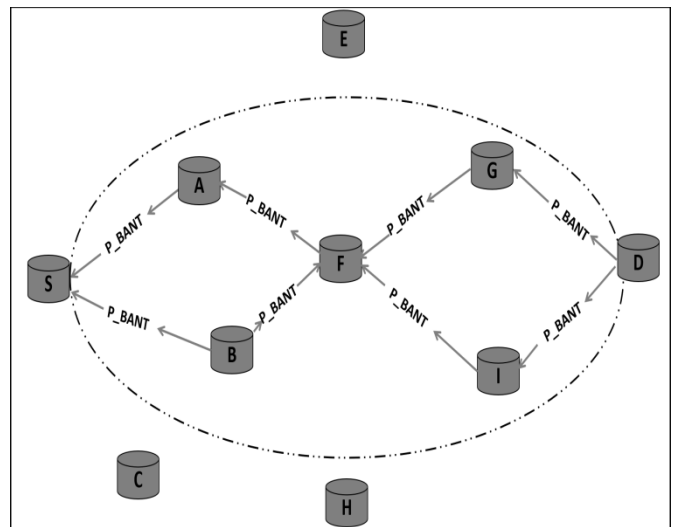


Fig. 3.    PADR - P BANT propagation.

### B. Route Maintenance

By balancing the pheromone concentration, the second phase of the PADR algorithm includes a route management procedure that keeps track of active and updated routes during data communications [24]. A link quality and activity are determined by its pheromone concentration. The link with the most data traffic has the highest pheromone levels, whereas the link with the least data traffic has the lowest.

$$\frac{(x-h)^2}{a^2} + \frac{(y-k)^2}{b^2} \ \le 1 \tag{4}$$

The analysis of the pheromone difference provides considerable information about the network status, as the authors have already investigated in [2] [6], the data path with the highest pheromone level is the one that draws the most traffic [27]. The routing processing component of the PAR [8] algorithm has been significantly improved to model the PADR. Assume the data flow between the source and destination is via S-A-F-G-D and S-A-F-I-D in the scenario depicted in Fig. 4. PADR proposes an alternative path when a node travels outside the ($P_w$) region, as shown in Fig. 5.
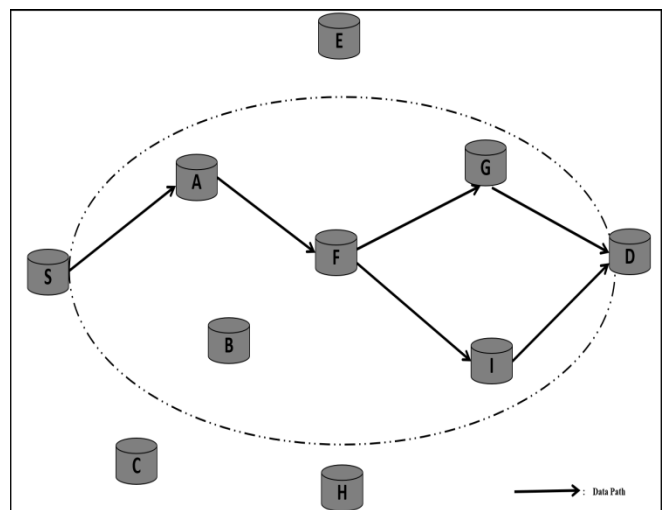


Fig. 4.    PADR - Data Path - 1.

**Onreceiving APacket()**
**if** *recvPADRPkt(Packet* p)* **then**
    **if** (*PADR_DATA_Packet*) **then**
        Increase the pheromone intensity between the intermediate link (i,j)
        **if** *intermediate node observe the link breakage between node link (i,j)* **then**
            Change the pheromone value from i – j to zero
            Broadcast link failure message to all nodes
            Source node tries to obtain alternative path to destination
            **if** (*Source found alternative path*) **then**
                Start sending data packet on the new path
            **else**
                Source initiate new route discovery process
            **end**
        **else**
            **if** (*Intermediate node lies inside $P_w$*) **then**
                Intermediate node increase the pheromone intensity in the link (i,j)
                Source continues to transmit the data packet on the same path
            **else**
                Change the pheromone value from i – j to zero
                Intermediate node drops the packet and does not forward the packet to its neighbor node
            **end**
        **end**
    **end**
**end**

**Algorithm 1: PADR Route Maintenance**

The PADR checks whether the mobile node is inside the ($P_w$) region using Eq. (4). PADR's data transmission is shown in Algorithm 1.
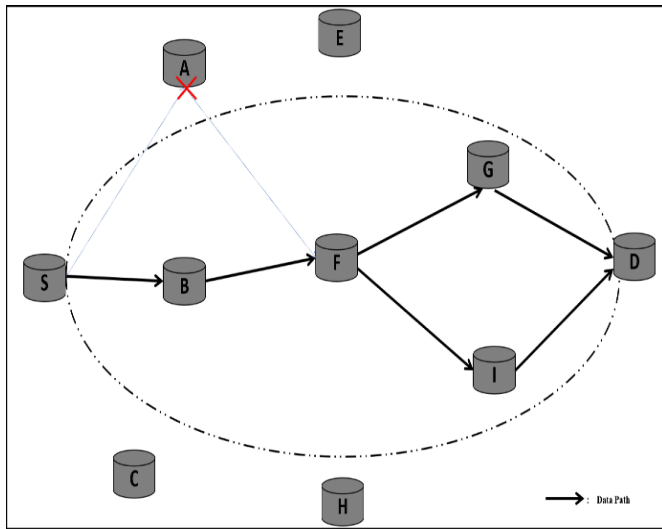


Fig. 5. PADR- Data Path – 2.

*C. Route Repair*

The PADR algorithm's third phase includes a route repair process, which is started when a broken path between end nodes is detected. Due to restricted resources such as inadequate signal strength, bandwidth, congestion, power outage, or failure of radio coverage, broken path situation in MANET might occur often, necessitating a rapid route setup

procedure during active data sessions [8]. PADR finds an alternative path inside the $\pi * a * b$ area if a broken path is discovered during an active data session. PADR initiates a new route discovery procedure if no path between source and destination is discovered.

## IV. RESULTS AND ANALYSIS

This section compares and evaluates the performance of the PAR, SARA, AODV, and proposed PADR algorithms in Network Simulator (NS2) running on Ubuntu Linux version 18.04. The ACO framework method is used in the PAR, SARA, and suggested routing algorithms, but the AODV is a normal traditional-based routing algorithm. The PAR coding implementation in NS2 version 2.35 has been improved to behave like PADR. A network of nodes ranging from 15 to 150 nodes dispersed across a 1000 x 1000 m geographic region was used to test the proposed PADR. Table I lists the essential parameters and exact values used during the simulation investigation.

*A. Study of Packet Generation*

For the PADR, PAR, SARA, and AODV routing algorithms, Fig. 6 illustrates the total number of packets generated and sent by the source node to the destination across the network. The nature-inspired method creates more data packets than the conventional based routing technique, according to the simulation analysis of PADR, PAR, SARA, and AODV. When compared to the PAR, SARA, and AODV algorithms, the number of packets generated by the source node of PADR is higher because the source node receives a faster response from the destination for establishing a path through intermediate nodes, so the source starts transmitting

packets in the network right away. According to the graph in figure 6, the PADR creates 6.16% more packets on average than PAR, 9.61% more packets than SARA, and 26.5% more packets than AODV routing approaches.

TABLE I.      SIMULATION PARAMETERS

| Parameter | Values |
|---|---|
| Interface queue type | Queue/DropTail |
| Radio-propagation model | Propagation/TwoRayGround |
| Number of nodes | 15, 30, 50, 75, 100 & 150 |
| Channel | Channel/WirelessChannel |
| Simulation area Size | 1000 x 1000 |
| Simulation Time | 160s |
| Packet size | 512 bytes |
| Mac type | 802.11 |
| Node speed | 0 m/s to 10 m/s |
| Transport protocol | TCP |
| Routing protocol | PAR and PADR |
| link layer type | LL |
| Network interface | Phy/WirelessPhy |

### B. Study of Packet Received

For the PADR, PAR, SARA, and AODV routing algorithms, Fig. 7 depicts the total number of packets received by the destination node across the network. The routing algorithms PADR, PAR, SARA, and AODV are used. The nature inspired algorithm outperforms the classical based routing technique even at packet acceptance by the destination, according to the simulation analysis of PADR, PAR, SARA, and AODV. This is because in the ACO algorithm, the path with higher pheromones value attracts more data packets in the network. According to the graph in Fig. 7, the PADR's destination receives 11.12% more packets on average than PAR, 14.66% more packets than SARA, and 47.42% more packets than the AODV routing technique.
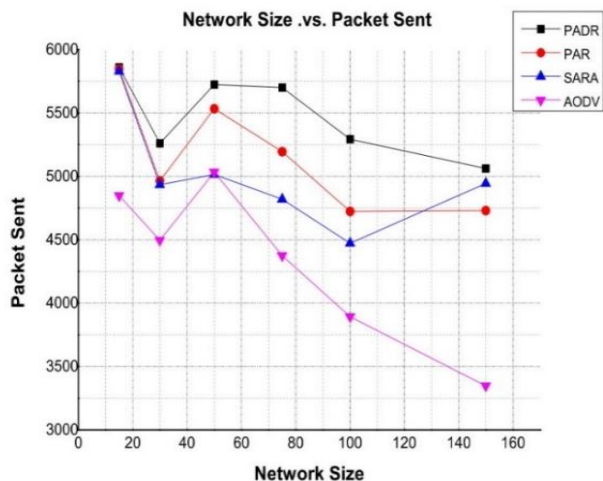


Fig. 6.   Network size vs. packet sent.
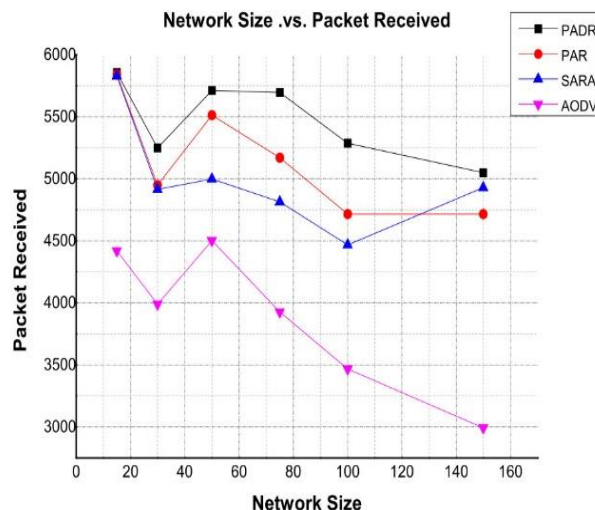


Fig. 7.   Network size vs packet received.

### C. Study of Packet Delivery Fraction (PDF)

The analysis for packet delivery fraction for PADR in comparison to PAR, SARA, and AODV approaches is shown in Fig. 8. There are two main reasons why an intermediate node cannot participate in data transmission in PADR. If the node is outside the $P_w$, the pheromone value of that nearby links is zero, and if node moves outside the Pw, the pheromone value of the neighboring links is zero. In the latter case, data packets from intermediate (upstream and downstream) nodes with the connection value zero are deleted. The delivery rate of data packets is high in PADR because each node traverses all of the data packets within Pw. According to the graph in figure 8, PADR performs 0.103% better than PAR, 0.055% better than SARA, and 11.42% better than AODV routing technique.

### D. Study of End-to-End Delay

The end-to-end latency of PADR is shown in Fig. 9 in comparison to PAR, SARA, and AODV routing techniques.
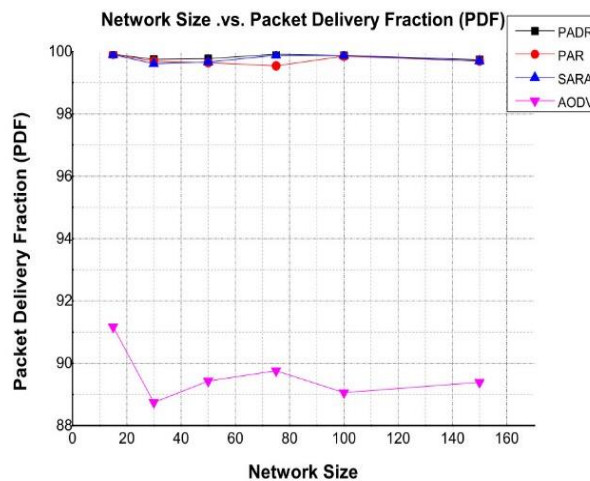


Fig. 8.   Network size vs. packet delivery fraction.
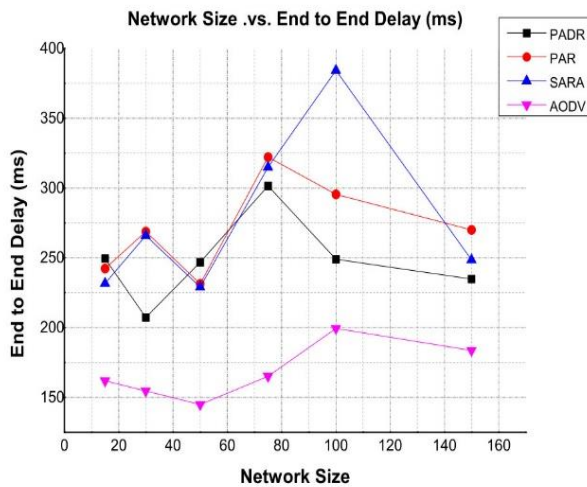
Fig. 9.   Network size vs. end-to-end delay.
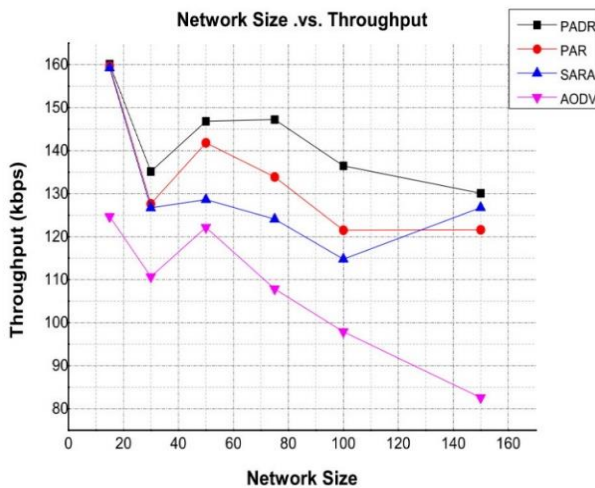


Fig. 10.  Network size vs. throughput.

Because the path with a higher pheromones value attracts more data packets, PADR has better end-to-end delay outcomes than PAR and SARA, but is slower than AODV. Pheromone concentration, on the other hand, lowers as time passes owing to pheromone evaporation. As a result, the ACO algorithm uses a restricted number of paths, which attracts an excess of traffic to the same routes, resulting in a nearly constant high end-to-end delay [2]. Because, in PADR, when a node with a data path travels outside of the $P_w$, the upstream node discovers an alternative path to downstream node within $\pi * a * b$ as shown in Fig. 5. As a result, PADR has a lower delay and latency than PAR and SARA routing approaches. The end-to-end delay of PADR is 8.65% less than PAR, 11.06% less than SARA, and 47.45% more than AODV routing approach, according to the graph in Fig. 9.

### E.  Study of Throughput

The throughput represents the path's quality and the number of data packets delivered to the destination during a given period of time. The throughput of PADR is shown in Fig. 10 in comparison to PAR, SARA, and AODV routing

techniques. In comparison to PAR, SARA, and AODV routing, PADR gives superior throughput simulation time, according to the simulation data. PADR gives an average of 6.17% more throughput than PAR, 9.69% more than SARA, and 32.50% more than AODV routing approach, according to the graph in Fig. 10.

### F.  Study of Routing Overheads

The routing overhead of PADR is shown in Fig. 11 in comparison to PAR, SARA, and AODV routing algorithms. PADR has slightly greater overhead than PAR and SARA, but less than AODV, according to the simulation results. Because nodes move beyond the $P_w$, PADR considers extra Pw computation during route maintenance sessions, the overhead in PADR is slightly higher. Despite the fact that PADR consumes more overhead than PAR and SARA, it outperforms them in all of the listed measures.
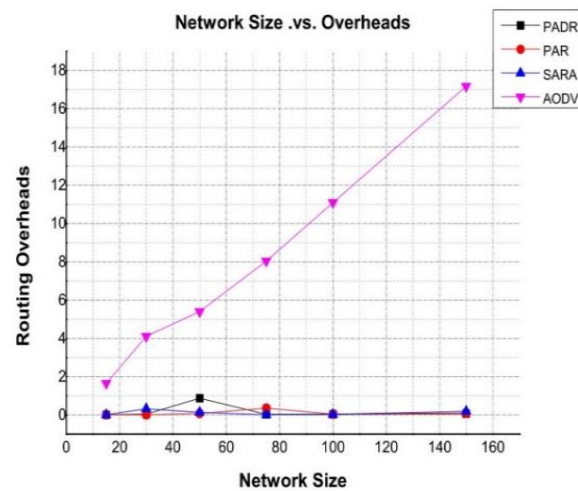


Fig. 11.  Network size vs. routing overheads.

### V.   CONCLUSION

This research article introduces Petal Ant Dynamic Routing (PADR), an upgraded version of a nature-inspired method. The proposed work's major goal is to improve Quality of Service (QOS) in terms of performance, throughput, and networking latency. The proposed routing is simulated in NS 2.35 and compared to MANET routing domain related work. According to the simulation results, PADR outperforms AODV, SARA, and PAR in terms of packet generation, packet delivery fraction (PDF), end-to-end delay, and throughput, while using PADR slightly higher routing overheads than PAR.

REFERENCES

[1]  M. Gunes, U. Sorges and I. Bouazizi, "ARA-the ant-colony based routing algorithm for MANETs," Proceedings. International Conference on Parallel Processing Workshop, Vancouver, BC, Canada, 2002, pp. 79-85, doi: 10.1109/ICPPW.2002.1039715.

[2]  Wang, Hua, et al. "An optimized ant colony algorithm based on the gradual changing orientation factor for multi-constraint QOS routing." Computer Communications 32.4 (2008): 586-593. https://doi.org/10.1016/j.comcom.2008.11.017

[3]  Wang, Jianping, et al. "HOPNET: A hybrid ant colony optimization routing algorithm for mobile ad hoc network." Ad Hoc Networks 7.4 (2009): 690-705. https://doi.org/10.1016/j.adhoc.2008.06.001

[4] Correia, Fernando, and Teresa VazEo. "Simple ant routing algorithm strategies for a (Multipurpose) MANET model." Ad Hoc Networks 8.8 (2010): 810-823. https://doi.org/10.1016/j.adhoc.2010.03.003

[5] Dressler, Falko, and Ozgur B. Akan. "A survey on bio-inspired networking." Computer Networks 54.6 (2010): 881-900. https://doi.org/10.1016/j.comnet.2009.10.024

[6] Karia, Deepak C., and Vaibhav V. Godbole. "New approach for routing in mobile ad-hoc networks based on ant colony optimization with global positioning system." IET networks 2.3 (2013): 171-180. DOI: full/10.1049/iet-net.2012.0087

[7] Singh, Gurpreet, Neeraj Kumar, and Anil Kumar Verma. " Antalg: An innovative ACO based routing algorithm for MANETs." Journal of Network and Computer Applications 45 (2014): 151-167. https://doi.org/10.1016/j.jnca.2014.07.006

[8] Manjunath, M., and D. H. Manjaiah. "PAR: Petal Ant Routing Algorithm for Mobile Ad Hoc Network." International Journal of Computer Networks & Communications 7.2 (2015): 45. https://doi.org/10.48550/arXiv.1504.04420

[9] Banerjee, Saptarshi, et al. "Modified Ant Colony Optimization (ACO) based routing protocol for MANET." Computing and Communication, 2015 International Conference and Workshop on. IEEE, 2015. DOI: 10.1109/IEMCON.2015.7344473

[10] Manjunath M and Manjaiah D.H, "Stipulated Region Based Routing (SRR) algorithm for Mobile Ad Hoc Network," 2015 International Conference on Soft-Computing and Networks Security (ICSNS), Coimbatore, India, 2015, pp. 1-6, doi: 10.1109/ICSNS.2015.7292419.

[11] Jayalalitha, B., and P. Chenna Reddy. "Design of an ANT based routing algorithm for mobile ad-hoc networks." Communication and Electronics Systems (ICCES), International Conference on. IEEE, 2016. DOI: 10.1109/CESYS.2016.7889850

[12] Manjunath, M., and D. H. Manjaiah. "SS PAR: Signal Strength Based Petal Ant Routing Algorithm for Mobile Ad Hoc Network." Emerging Research in Computing, Information, Communication and Applications. Springer, New Delhi, 2016. 207-217. http://dx.doi.org/10.1007/978-81-322-2553-9_20

[13] Zhou, Jipeng, et al. "Ant colony-based energy control routing protocol for mobile ad hoc networks under different node mobility models." EURASIP Journal on Wireless Communications and Networking 2016, DOI: https://doi.org/10.1186/s13638-016-0600-x

[14] B. P. Sathyaprakash, M. Jayaprasad and M. Manjunath, "I-PAR: Improved Petal Ant Routing Algorithm for Mobile Ad-Hoc Networks," 2017 2nd International Conference on Computational Systems and Information Technology for Sustainable Solution (CSITSS), Bangalore, 2017pp.1-5. DOI: 10.1109/CSITSS.2017.8447759

[15] Yadav, Ajay Kumar, Santosh Kumar Das, and Sachin Tripathi. "EFMMRP: Design of efficient fuzzy based multi-constraint multicast routing protocol for wireless ad-hoc network." Computer Networks, DOI: https://doi.org/10.1016/j.comnet.2017.03.001

[16] Sarkar, Dipika, Swagata Choudhury, and Abhishek Majumder. "Enhanced-Ant-AODV for optimal route selection in mobile ad-hoc network." Journal of King Saud University-Computer and Information Sciences (2018). https://doi.org/10.1016/j.jksuci.2018.08.013

[17] M. B. Dsouza and M. D.H., "Energy Aware Simple Ant Routing Algorithm for MANET," 2020 5th International Conference on Communication and Electronics Systems (ICCES), Coimbatore, India, 2020, pp. 381-385, doi: 10.1109/ICCES48766.2020.9137947.

[18] V. Alappatt and P. M. Joe Prathap, "A Hybrid Approach Using Ant Colony Optimization and Binary Particle Swarm Optimization (ACO: BPSO) for Energy Efficient Multi-path Routing in MANET," 2020 Advanced Computing and Communication Technologies for High Performance Applications (ACCTHPA), Cochin, India, 2020, pp. 175-178, doi: 10.1109/ACCTHPA49271.2020.921319

[19] Suresh, Salini, et al. "A Comparative Performance Analysis of AOMDV and PAR Algorithms for Mobile Ad Hoc Networks." Proceedings of the 2nd International Conference on Computational and Bio Engineering:2020. https://doi.org/10.1007/978-981-16-1941-0_58

[20] Sarkar, Dipika, Swagata Choudhury, and Abhishek Majumder. "Enhanced-Ant-AODV for optimal route selection in mobile ad-hoc network." Journal of King Saud University-Computer and Information Sciences 33.10 (2021): 1186-1201. https://doi.org/10.1016/j.jksuci.2018.08.013

[21] Kumari, P., Sahana, S.K. (2021). QoS-Based ACO Routing Protocols in MANETs: A Review. In: Nath, V., Mandal, J.K. (eds) Proceedings of the Fourth International Conference on Microelectronics, Computing and Communication Systems. Lecture Notes in Electrical Engineering, vol 673. Springer, Singapore. https://doi.org/10.1007/978-981-15-5546-6_27

[22] Dash, Yajnaseni. "Nature inspired routing in mobile ad hoc network." 2021 3rd International Conference on Advances in Computing, Communication Control and Networking (ICAC3N). IEEE, 2021. DOI: 10.1109/ICAC3N53548.2021.9725366

[23] Karmel, Arockiasamy, et al., "Ant-based efficient energy and balanced load routing approach for optimal path convergence in MANET." Wireless Networks 27 (2021): DOI: https://doi.org/10.1007/s11276-019-02080-w

[24] Sharma, Arush S., and Dongsoo S. Kim. "Energy efficient multipath ant colony-based routing algorithm for mobile ad hoc networks." Ad Hoc Networks 113 (2021): 102396. https://doi.org/10.1016/j.adhoc.2020.102396.

[25] S. K. Srivastava and A. Agarwal, "Implementation of Ant Colony Optimization Algorithm for Load Balancing Routing in MANET Network," 2022 Second International Conference on Advanced Technologies in Intelligent Control, Environment, Computing & Communication Engineering (ICATIECE), Bangalore, India, 2022, pp. 1-6, doi: 10.1109/ICATIECE56365.2022.10046688.

[26] Sinwar, Deepak, et al. "Analysis and comparison of ant colony optimization algorithm with DSDV, AODV, and AOMDV based on shortest path in MANET." Journal of Information and Optimization Sciences, DOI: 10.1080/02522667.2020.1733193

[27] Nagendranth, M. V. S. S., et al. "Type II fuzzy-based clustering with improved ant colony optimization-based routing (t2fcatr) protocol for secured data transmission in manet." The Journal of Supercomputing 78.7 (2022): 9102-9120.

[28] U. Srilakshmi, S. A. Alghamdi, V. A. Vuyyuru, N. Veeraiah and Y. Alotaibi, "A Secure Optimization Routing Algorithm for Mobile Ad Hoc Networks," in IEEE Access, vol. 10, pp. 14260-14269, 2022, doi: 10.1109/ACCESS.2022.3144679.

[29] Madan H. T. and Prabhugoud I. Basarkod, "Reliable and Secrecy Aware Cooperative Framework for Cognitive Radio Non-Orthogonal Multiple Access (NOMA) Networks," Journal of Communications vol. 17, no. 2, pp. 125-133, February 2022. Doi: 10.12720/jcm.17.2.125-133

[30] L Rajesh & Dr. Mohan H S, "Adaptive Group Teaching Based Clustering and Data Aggregation with Routing in Wireless Sensor Network.", published in Wireless Pers Commun 122, 1839–1866 (2022). https://doi.org/10.1007/s11277-021-08971-6

[31] L Rajesh & Dr. Mohan H S, "An multilevel efficient energy clustering protocol with secure routing (MEECSR) in WSNs" Published in International Journal of Applied Science and Engineering, volume-18, 2020344,2021. URL link: https://doi.org/10.6703/IJASE.202106_18(2).008

# Hybrid Syntax Dependency with Lexicon and Logistic Regression for Aspect-based Sentiment Analysis

Mohammad Mashrekul Kabir, Zulaiha Ali Othman, Mohd Ridzwan Yaakub, Sabrina Tiun

Universiti Kebangsaan Malaysia (UKM), Bangi 43600, Selangor, Malaysia

*Abstract*—**Aspect-based Sentiment Analysis (ABSA) is a fine-grained form of SA that greatly benefits customers and the real world. ABSA of customer reviews has become a trendy topic because of the profuse information that is shared through these reviews. While SA also known as opinion mining helps to find opinion, ABSA greatly impact business world by converting these reviews to finer form with aspects and opinion or sentiment. These review words are interwoven internally, which depends on the semantics besides syntax, and sometimes there are long dependencies. Recently, the hybrid methods for ABSA are popular, but most of them merely considered if the syntax and long dependency exist, thus missing the inclusion of multi and infrequent aspects. In addition, in most literature, sentiment classification is shown directly without calculating the sentiment scores in ABSA. To this effect, this paper proposes a hybrid with syntax dependency and the lexicon for aspect, sentiment extraction, and polarity classification by Logistic Regression (LR) classifier to overcome the issues in ABSA. The proposed method is able to address the challenges of ABSA in a number of ways. First, it is able to extract multi-word and infrequent aspects by using syntactic dependency information. Second, it is able to calculate sentiment scores, which provides a more nuanced understanding of the overall sentiment expressed towards an aspect. Third, it is able to capture long dependencies between words by using syntactic dependency and semantic information. The proposed hybrid model outperformed the other methods by an average of 8-10 percent with the standard public dataset in terms of accuracy.**

*Keywords*—*Aspect-based Sentiment Analysis; dependency parsing; lexicon; customer review; opinion mining, hybrid*

## I. INTRODUCTION

The extensive growth of the Internet resulted in an evolution in online businesses. The statistics show that the tourism industry's GDP earnings constantly increase between 6% and 10%, which shows tourists' growth [1]. Due to this growth, there is an extraordinary volume of data that includes customer reviews that can be explored to get customer feedback on products or services. Reviews focus on comments or opinions that provide prospective customers with insightful information. Most people are impacted by opinions, particularly product ratings, which have proven to affect customer behaviour. Moreover, web-based information is more accurate and trusted than that supplied by the manager or product supplier [2], which needs to process through sentiment analysis.

Earlier literature only focused on sentiment analysis (SA) or opinion mining [3-14], without aspects. Later, Bing Liu (2012) provided the latest definition of aspect-based SA. According to Liu (2012), 'an opinion is defined as a quintuple' (ei, aij, sijkl, hk, tl), where e is an entity, a is an aspect, and s is sentiment [15]. This provided the foundation of Aspect-based Sentiment Analysis (ABSA). In Aspect-based Sentiment Analysis, deriving aspects and their sentiment or opinion from these text paragraphs is challenging. It is necessary to recognize and connect specific texts for aspects and to look for particular sentiments to derive aspect-based sentiment analysis. For instance, a restaurant review may read, "Foods are wonderful, but the location is awful." The review remarks, in this case, focus on two aspects. The "location" is one aspect, and the "food" is another. In this example, there are two opinion terms. They are both "wonderful" and "awful." Aspect-based Sentiment Analysis comprises three tasks. First is the identification of aspects, the second is the identification of its' sentiment or opinion terms, and last is the orientation detection of sentiment or opinion terms, that is, aspect sentiment classification. Three basic methods are used for ABSA tasks: machine learning-based method, dictionary-based, and hybrid method [16–18].

In the first ABSA task of aspect extraction, there are at least two problems. First is the difficulty of multi aspects extraction. For example, in the review- "The hotel is perfectly located, with good rooms, but we could not eat the food; it was tasteless". In this review, a traveler expresses opinions on multi aspects, such as location, rooms, and food are highlighted in the review. Secondly, extracting infrequent aspects, for example, Wi-fi, swimming pool, and car parking, are less frequent, but these have significant importance in the hotel and restaurant domain. There isn't a single solution in the available aspect identification methods [19-29] that adequately addresses all of the aforementioned aspect identification concerns. Therefore, there is a need for a solution to address these difficulties collectively. Different methods have been offered in the literature for each issue. This inspired us to devise a method for single-aspect extraction that can handle multi and infrequent aspects.

Similarly, in second ABSA task of sentiment classification of recognized aspects, issues with managing multi-aspect reviews exist. Since numerous aspects of a review are presented, and each is favorable or negative, classifying multi-aspect reviews is difficult. Each aspect can have a positive or

negative sentiment among multiple aspects discussed in a review. Thus, classifying multi-aspect reviews is difficult. For example, let us analyze the following quote from a hotel review: "Our room was very pleasant, but the hotel staff was rude. An ideal location for a family with children, offering a clean bathroom and lovely views". The reviewer expresses opinions on the "staff," "room," and "location", among other things. The review demonstrates that different parts have varied sentiments, with 'staff' having a negative and 'room' and 'location' having a positive sentiment.

This challenge of sentiment classification of multi-aspects has not been addressed by the methods presented in the literature [24, 30-36]. To our knowledge, no machine learning (ML)-based approach is currently available for aspect classification that successfully manages this challenging issue. Therefore, we contend that aspect-based sentiment classification can only improve if aspect classification methods can effectively handle multi-aspect problems.

In this article, we propose an aspect-based sentiment classification framework, and our contributions are three-fold; (1) a hybrid method, an extension of syntax, and dependency - based has been proposed for multi-aspect extraction; (2) a method has been devised for accurate identification of infrequent aspects and (3) an effective mechanism with classifier has been developed for calculating reviews score and decide the polarity for classification of aspects. To do this, it put forward a model that used hybrid syntax, lexicons and dependency parsing to extract user aspects, sentiments, and reviews of sentiments. A lexical dictionary called SentiWordNet helps determine each opinion word's positive and negative polarity values [38-40].

There are six sections to this paper. Section II presents the related works. The study methodology is shown in Section III. The performance findings of the experiment and results are described in Sections IV and V respectively.. The research implications and the summary of the study are presented in the last section, in Section VI.

## II. RELATED WORKS

Aspect-based Sentiment Analysis can be divided into two primary tasks: aspect extraction and aspect-based sentiment classification. There are three fundamental methods for aspect-based sentiment analysis: machine-learning-based, dictionary-based, and hybrid methods. The machine learning based method includes a wide range of various rules-based, seed-based, and supervised methods. Rules-based uses importance score and frequency of occurrence to identify aspects. Jime'nez-Zafra et al. [19] have suggested a method that uses a bag of words with aspect terms based on frequency using the Freebase dataset, including tourism. In this method, aspects were compiled from the lexicon and rated by how often they appeared in reviews. Wang et al. [21] have suggested a part-of-speech (POS) tagger method. Frequent morphological and inflexional ends were eliminated using a unique Porter stemming method to pick the possible aspects. This method was used to quickly and automatically identify words with identifiable spellings. Afzaal et al. [24] suggested a better approach based on fuzzy-based learning. This approach involved extracting frequent nouns and noun phrases from the

reviews. But this could not address multi aspects. Despite being simple to use and effective in the identification process, rule-based methods do not address some issues. For instance, rule-based approaches generate small rules, extract irrelevant aspects, and cannot identify infrequent aspects.

Seed-based method use grammatical relationships between seed sets and review terms to identify key aspects. [25] produced a seed set for each of the five most frequent aspects from reviews, using the co-occurrence of various words. This helps to identify the key aspects of a review. Mukherjee et al. [26] suggested a seed-based strategy to determine semantic relationships between review terms. Kayaalp et al. [27] proposed a three-step seed-based feature extraction technique. First, choose the top four restaurant review topics-—food, service, price, and ambience; second, properly tag and index terms; and lastly, classify indexed words based on proximity. Seed-based approaches lack consideration of review words' links, require in-depth topic expertise, and are insufficient for covering entire domains. For instance, the whole domain of a normal hotel or restaurant cannot be covered by food, service, pricing, and ambience since this domain comprises many other vital aspects.

The supervised method predicts sentiment as a combination of themes using topic model-based approaches. Wu et al. [28] utilized a combined probabilistic model to identify aspects based on overall importance, user importance, and likelihood of inclusion in multiple aspect sentiments. Shams et al. [29] proposed an enhanced LDA model using co-occurrence associations for precise aspects of reviews.

After aspect extraction, the aspect sentiment classification literature is reviewed. This task consists of two subtasks: first, sentiment word extraction and then, determining polarity or ABSA. This task also uses three methods: ML, Lexicon and hybrid method. Mubarok et al. [30] used a three-step ML model for classification tasks, pre-processing reviews, applying feature selection using chi-square, and dividing reviews into polarity classes using Naive Bayes classifier. The model achieved 77% accuracy in aspect-based classification. Xu et al. [31] use SVM for ML-based techniques in traveller reviews to predict sentiments about several aspects of reviews. [32] utilized sentence-level reviews of electrical devices and mobile phones for classification after statistical aspect extraction. [33] processed reviews, cleaned, stemmed extracted features and predicted polarity using the BOW model. The literature in [34] used sophisticated pre-processing techniques, including tokenization, word removal, filtering, stemming, and sentiment classification. The research in [35] method involves pre-processing, phrase extraction, BOW extraction, sentiment score calculation, and classification. The procedure involved in [36] were pre-processing, feature extraction, classifier training, testing, and labelling tweets. In [38], document classification methods involved pre-processing, segmentation, feature extraction and SVM.

The second method uses dictionary-based sentiment analysis using lexicon, like SentiWordNet. The literature [41], used pre-processed data using tokenization, removing stop words, noise, duplicates, missing values, and stemming. Sentiment polarity detection was performed using

SentiWordNet, while sentiment classification features included chunking, segmentation, and N-grams. The study in [42] utilized pre-processing techniques, hyper-parameter selection, word vector representation for aspects, and CBOW and skip-gram models for sentiment classification.

In the third sentiment classification method of ABSA, Santhosh et al. [43] used POS tag for aspect-opinion pair formation, and final polarity detection. Nisha et al. [44] used a hybrid with unsupervised ML method LDA with lexicon. Kushal et al. [45] used text formatting with fuzzy matching and domain grouping of synonym words, aspect extraction with POS tagging, association mining and probabilistic approach, opinion extraction with words extraction, and final polarity detection for aspect-opinion pair, and aspect-based summarization. Wu et al. [46] used a hybrid with supervised and dependency POS tagging features, but it cannot extract multiple aspects and doesn't calculate the score of sentiment words.

A chunk-level extraction technique was developed by Wu et al. [47] combined a hybrid of rule-based and supervised learning methodologies to extract neutral aspects of ABSA but could not identify multi aspect. Zainuddin et al. [48] proposed a hybrid sentiment classification approach using Twitter datasets to improve the Twitter Aspect-based Sentiment Analysis using association rule mining (ARM) and a rule-based dependency parser. This hybrid used a dependency parser but missed syntax, therefore, could not find multi aspect. Later, Akhtar et al. [49] hybrid used Conditional Random Field (CRF) and Support Vector Machine (SVM) in the Hindi language. Hu Liu's [50] benchmarking literature combined POS tag and Association Rule Mining to detect the most frequent noun aspects. Zhou et al. [51] used a hybrid with semi-supervised learning algorithm to capture cross-domain features.

The literature above shows different combinations of hybrid, the first one [37] with unsupervised ML method LDA and lexicon. [47] and Hu Liu [50] used POS tags with association rule mining to detect frequent noun aspects, but this literature cannot address infrequent aspects. The study in [51] used a hybrid with semi-supervised learning algorithm. The authors in [46] used hybrid with supervised and dependency POS tagging features. But it could not address multi aspect. Zainuddin's hybrid added dependency parser with association rule mining, but it lacked to find grammatical relationships with syntax, thus missing multi-aspect and infrequent aspects.

These challenges inspired us to develop a technique to handle these difficult aspect extraction situations. This paper proposed a novel hybrid with syntax, dependency, Lexicon and classifier to solve the multi aspects extraction, including infrequent aspects.

## III. PROPOSED HYBRID MODEL

The proposed hybrid model is shown in Fig. 1. The suggested system is divided into four main phases: pre-processing phase; aspect extraction phase; extraction of sentiment words; and finally, sentiment polarity calculations and sentiment classification. The suggested system accepts as input a text (or review) that has been divided up into sentences.

The system pre-processes the input sentences and parses them using a dependency parser, which offers a morphological analysis of each word in the phrase and a dependency structure for the sentence. The algorithm uses POS data and the polarity lexicon SentiWordNet (SWN) to extract the pertinent features and sentiment words. The algorithm then creates a dependency graph for the sentence, aiding in the execution of aspect-based SA. The sentiment word is allocated to the specific aspect, with the shortest distance from the aspect word based on the premise that closely related words combine to create a sentiment toward a particular feature. The proposed hybrid model for aspect sentiment classification is shown in Fig.1.
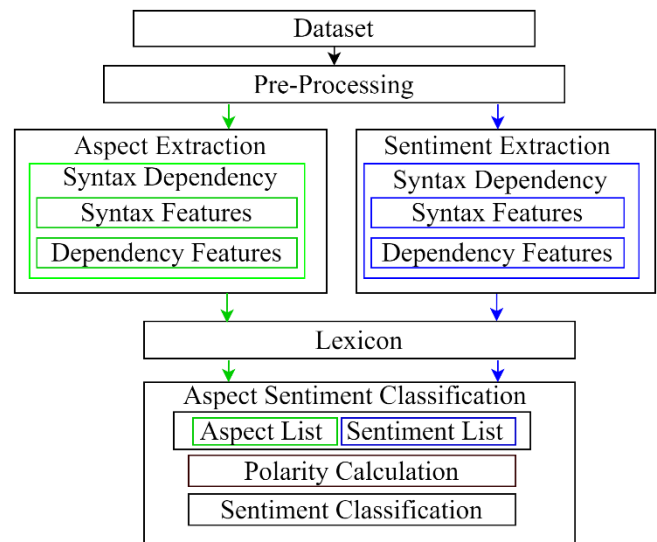


Fig. 1. Proposed hybrid Model for aspect sentiment classification.

The model has four major phases as preprocessing, aspect extraction, sentiment extraction and aspect sentiment classification. These are discussed below:

### A. Pre-processing

Data was gathered from a public dataset of customer reviews from hotels (in Europe and the US). This dataset was pre-processed. This paper used the NLTK library of Python for data preprocessing. This data preprocessing is a critical step that includes cleaning and formatting the data before feeding it into the ML algorithm. For NLP, the preprocessing steps had the following tasks: tokenizing the string, lowercasing, removing stop words, and stemming. Tokenization is used to split the strings into individual meaningful tokens. For the tokenization, NLTK module is used. Then, we converted each word in the string to lowercase. The next step is to remove stop words that do not add significant meaning to the text, such as 'I', 'we', 'own', and 'only', using the NLTK list. Next, stemming is performed, converting a word to its most general form, or stem. NLTK's porter stemmer is used to reduce the size of our vocabulary; for example, the 'using' word stems from 'use'.

### B. Aspect Extraction Phase

This model aims at Aspect-based Sentiment classification task of ABSA but for that it needs to derive aspects. Aspects may be one or many words that typically refer to nouns and noun phrases. The process for aspect extraction is described for

clarity. This paper used a hybrid method with syntax, dependency parsing and lexicon for aspect extraction which is described below:

*1) Syntax features:* The syntax-based approach analyses sentence to seek the links between the words in a phrase to determine its grammatical structure. The difficulty in identifying connections between words is influenced by the structure and pattern of the phrases in a sentence. Words in customer reviews adhere to certain grammatical and linguistic conventions. Syntax based method used syntax-based features. After pre-processing, it first identifies each word's Part of Speech (POS) tag in each review line to extract the aspects. It selects NN (noun, singular), NNS (noun, plural), NNP (proper noun, singular), and NNPS (proper noun, plural) tagged terms from the review file as aspects, tokenizing the review texts using a POS tagger. The frequent aspect terms are extracted with a POS tagger with noun and proper nouns.

*2) Dependency parsing:* This hybrid method first finds frequent aspects. For infrequent aspects, this paper used dependency parsing. The dependency parser is used to identify specific relations, which help determine infrequent aspects. Therefore, the author used nsubj (nominal subject), amod (adjectival modifier), advmod (adverbial modifier) and xcomp (casual component with external subject).

*3) Lexicon:* One important stage in the process of analysing text sentiment is matching aspect terms to a lexicon. The aspect words are matched to the Lexicon. The most popular lexicon SentiWordNet is used here due to its rich vocabulary. SentiWordNet stands out among the numerous lexicons accessible because of its large vocabulary and thorough coverage. Wide-ranging words are included in SentiWordNet, which assigns them sentiment ratings based on their positive, negative, and neutral meanings. A more detailed comprehension of the underlying sentiment in a given text is made possible by the sentiment analysis algorithms' ability to assign sentiment values to aspect words thanks to this broad vocabulary. Sentiment analysis algorithms may more accurately capture the finer details of sentiment conveyed in natural language by using SentiWordNet's lexical resources.

## C. Sentiment Extraction Phase

The important stage in ABSA is to detect and extract opinion words. Opinion words convey a person's opinion on a subject; therefore, it is essential to identify aspect-related opinion terms at this phase. It consists of syntax features, dependency parser and Lexicon module.

*1) Syntax features:* The author finds the opinion words using POS tagging with adjective words. According to Hu Liu (2004), the most opinion words are adjectives. Study suggests that adjectives and adverbs are effective markers of subjectivity and views [48]. An adjective that modifies a noun or noun phrase that is frequently present in aspect-based extraction is referred to as being close. Consequently, if such an adjective is present, it is regarded as a sentiment or opinion term.

*2) Dependency parser:* For infrequent sentiment words, we use a dependency parser. These can be adverbs and verb combinations. Later, the opinion orientation for each aspect was determined. When the context of a sentence is determined, the patterns are separated into segments, such as adjective-noun, adverb-adjective, noun-noun, noun-adjective, and adverb-verb combinations.

*3) Lexicon:* SentiWordNet, a lexicon of opinion words, was used, which aids in identifying each word's positive and negative polarity meaning and scores. Each synset of Wordnet words has been given positive and negative scores. When the context of a sentence is determined, the patterns are separated into segments, such as adjective-noun, adverb-adjective, noun-noun, noun-adjective, and adverb-verb combinations.

## D. Aspect Sentiment Classification

This model aims at aspect-based sentiment classification task of ABSA but for that it needs to derive aspects. Aspects may be one or many words that typically refer to nouns and noun phrases. The process for aspect extraction is described for clarity. This paper used a hybrid method with syntax, dependency parsing and lexicon for aspect extraction which is described below.

*1) Calculation of sentiment polarity:* Some literature, compute a sentiment score for each sentence and then link that sentiment to every aspect that is addressed in that sentence when performing sentiment analysis. However, this makes it impossible to handle phrases correctly when they contain aspects with multi sentiments. Therefore, this hybrid method suggests a system in which every sentence is divided into segments, each of which is assigned to a different aspect of the sentence. The polarity of each segment is then established using a sentiment lexicon, and an aspect-polarity pair is created that reflects the overall polarity for this aspect inside a specific review. SentiWordNet is used for aggregating opinions using the sentence's cumulative score. First, aspects are mapped to opinions, and an aspect opinion pair is formed. The opinion words are matched to the opinion lexicon in SentiWordNet, and the score is calculated. Table I shows calculation of sentiment score. The reviews has one aspect but multi opinion, the 'food' is the aspect and the first opinion 'very good' is positive. The score is 0.91 and the second opinion word of food is 'expensive' which is negative so the score is -0.50.

Table II shows calculation of polarity. At first scores are calculated and negative scores are subtracted from positive, thus the final score is calculated.

TABLE I. CALCULATION OF SENTIMENT SCORE

| Review | Aspect Opinion | Score | Total Score |
|---|---|---|---|
| food is very good but expensive | {'aspect': 'hotel', 'opinion': 'very good'} | 0.91 | +0.41 |
| food is very good but expensive | {'aspect': 'hotel', 'opinion': 'expensive'} | -0.50 | |

TABLE II.      CALCULATION OF POLARITY

| Review | Total Score | Accumulated Polarity |
|---|---|---|
| food is very good but expensive | (+0.91-0.50) = +0.41 | **Positive** |

*2) Handling negations:* The words and phrases known as "opinion shifters" may cause a user's view to shift from favourable to negative or vice versa. The most frequent opinion-shifting words are: not, neither, nobody, none, nowhere, and cannot. For instance, a client may write in their review, "I am not satisfied with the time they take to deliver the purchase." The word satisfied has a positive valence in this statement. However, it contains the negative "not." The polarity of the whole phrase shifts from positive to negative due to the existence of this negative word. Table III & Table IV, showing calculation of sentiment score with negations and polarity.

TABLE III.      CALCULATION OF SCORE (HANDLING NEGATIONS)

| Review | Aspect Opinion | Score |
|---|---|---|
| there is **not** very good food items | {'aspect': 'food items', 'opinion': 'not very good'} | -0.26 |

TABLE IV.      CALCULATION OF POLARITY (HANDLING NEGATIONS)

| Review | Score | Accumulated Polarity |
|---|---|---|
| there is not very good food items | -0.26 | Negative |

*3) Sentiment classification:* The entire number of aspects, together with their sentiment scores, will be calculated, aggregating the sentiment scores of all the opinion terms. At first, aspects' positive and negative scores were individually recorded. As a result, we get the total positive and negative scores for that aspect. These findings created a sentiment profile for each restaurant or product. The scores for each aspect may be added up using the method below. For each jth aspect of the review,

Accumulated_Positive _polarity[j] = Σi Positive_Poly, j

Accumulated_Negative _polarity[j] = Σi Negative_Poly,j

After this, the data was divided into training and test data. Accumulated polarity information from Table III and Table IV above is fed. Finally, classifiers trained with training data and it carry out classification with test data.

*E. Performance Evaluation Measures*

To assess the overall classification performance using binary classes, we employ accuracy metrics (positive and negative). This paper uses the common assessment metrics of precision, accuracy and recall for both positive and negative feelings about things. Based on the output of the confusion matrix, this research employed four efficient measures: True Positive (TP), False Positive (FP), True Negative (TN), and False Negative (FN) [48].

## IV.   EXPERIMENT

The experiment is implemented using Python, version 3.7. The hotel reviews datasets of Europe & the US hotels are used in the experiment.

*A. Dataset*

This research has collected hotel data from a public dataset of hotel reviews in Europe & the US. The dataset used is huge (515k hotel reviews), containing 515,000 customer reviews and scoring 1493 luxury hotels across Europe & the US [52]. The data was scraped from Booking.com. This data is in an unstructured format in CSV and contains 17 fields, such as: hotel address, review date, Average Score, Hotel Name, Reviewer Nationality, Negative review, Review Total Negative Word Counts, Positive Review, Review Total Positive Word Counts, Reviewer Score, Total Number of Reviews Reviewer Has Given, Total Number of_ Reviews, Tags, Days since review, Additional Number of_ Scoring, lat, and lng.

## V.   RESULTS AND DISCUSSION

The experiment entailed examining the performance levels of the hybrid with classifiers, where the input features included review texts and the output was sentiment classification with aspect's sentiment summary (aspect based). Here this paper gives two-fold results for better understanding. The first one is comparison of the proposed model with other literature and the second is on the application of the result in hotel where, a comparison is made between aspects of various hotels. The hybrid method creates a training set first and then annotates the training data. The training data are then used to extract aspects, sentiments, and score calculating which are subsequently used for test dataset.

*A. Results*

The results shown are twofold. The first is the comparison of the proposed model in Table V and in Table VI, the valuable insights are enumerated.

*1) Comparison of the proposed model:* The comparative result is shown in Table V below. It is observed that, all hybrid of different combination results is measured with precision, recall and accuracy. The hybrid model of Wu et al. [46] with supervised and POS tagging had accuracy of 67.66%, where another literature of the same author with LDA and Lexicon achieved low result with accuracy 64.24%. Zainuddin used ARM and dependency, obtained better accuracy compared to the previous state-of-art method using Twitter dataset. Akhtar used CRF and SVM and it performed accuracy 54.05% (the lowest). Hu Liu literature hybrid with ARM and lexicon achieved better in recall as 80%, accuracy 75.8%. Zhou hybrid achieved the lowest performance with 46.55% in precision. The proposed hybrid used syntax dependency, lexicon and LR and achieved precision, recall and accuracy of 84.7, 86.6 and 84.2% respectively.

TABLE V.     COMPARISON WITH THE PROPOSED MODEL

| Refs. | Method | Measures (in percentage) | | |
|---|---|---|---|---|
| | | Precision | Recall | Accuracy/F1 |
| Wu et al. [46] | Hybrid (supervised+ POS tagging) | - | - | 67.66 |
| Wu et al. [47] | Hybrid (LDA and lexicon) | 58.94 | 70.59 | 64.24 |
| Zainuddin et al. [48] | Hybrid (ARM +dependency) | 77.9 | 76.6 | 76 |
| Akhtar et al. [49] | Hybrid (CRF and SVM) | - | - | 54.05 |
| Hu Liu [50] | Hybrid (ARM and lexicon) | 72 | 80 | 75.8 |
| Zhou [51] | Hybrid (semi-supervised learning + adversarial training) | 46.55 | 44.57 | - |
| Proposed model | Hybrid (Syntax Dependency+ lexicon and LR) | 84.7 | 86.6 | 84.2 |

*2) Experimental output of aspects and sentiments-the valuable insight of aspects:* A sample of 30 hotels with a total of 1057 user reviews is analysed for finding the sentiment score of the basic features of a hotel as "location", "services", "food". After frequency counts, five aspects are generated: food, location, comfort & facilities, staff, and value for money. The experimental output on four of the mentioned aspects, i.e., location, comfort & facilities, staff, and food are shown in Table VI. Location aspects in detailed (Year/ month wise) output is shown. The result of location aspects of five hotels' including the other aspects average (avg) is shown in the Table VI below.

TABLE VI.     COMPARISON OF VARIOUS ASPECTS AND BETWEEN HOTELS

| Hotel Name | Location (Year / Month wise) | | | | | | | | | | Comfort & Facilities (Avg) | Staff (Avg) | Food (Avg) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fairfield Inn | .55 | .45 | .46 | .93 | .74 | .65 | .55 | .78 | .82 | .77 | .65 | .74 | .55 |
| Little Paradise | .46 | .49 | .44 | .39 | .6 | .94 | .65 | .74 | .52 | .57 | .72 | .6 | .57 |
| Days Inn El Reno | .63 | .65 | .71 | .57 | .37 | .44 | .41 | .45 | .27 | .41 | .44 | .37 | .41 |
| Hawthorn Suites | .38 | .73 | .68 | .41 | .45 | .42 | .48 | .47 | .65 | .45 | .42 | .45 | .65 |
| Comfort Suites | .43 | .36 | .34 | .30 | .27 | .48 | .72 | .63 | .56 | .72 | .48 | .47 | .56 |

"Fig. 2", shows output comparison of location aspects between five hotels of USA. The location score is plotted in Y axis at a scale of 0 to +1, and X Axis shows the time (Year / Month). The average (avg) is calculated and shown beside the name of hotel. Fairfield Inn is number 1 (grey colour dash and dotted) hotel of US in terms of location, with average sentiment score 0.77, Little paradise (dotted lines) is the second hotel in US, followed by Days Inn El Reko (dash dash) with average 0.586, Hawthorn Suites is the fourth (average 0.516, and Comfort Suites is the fifth (ash colour) with average sentiment score 0. 486.Therefore from the result customer who looks for good location will choose Fairfield as it is the best.

Similarly, customer can choose hotel basing on his or her preference of aspects.
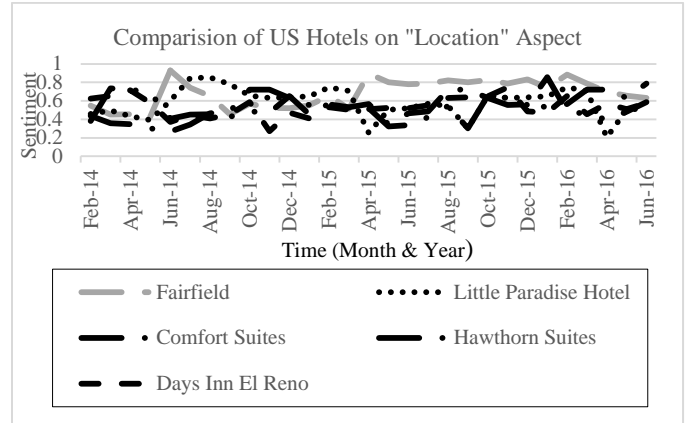


Fig. 2.  Comparison of "Location" aspect between US Hotels.

"Fig. 3", below shows sentiment Analysis & overall sentiment score of Hotel Comfort Suites. The Y axis shows the sentiment score from 0 to +0.8, and -0.8. The X axis shows time in Year & Month. This is the time of review. The dotted are expressed for positive and dashed are used for negative sentiment expression. Sentiment Analysis & overall sentiment score of Hotel Comfort Suites is shown in Fig. 3 below.
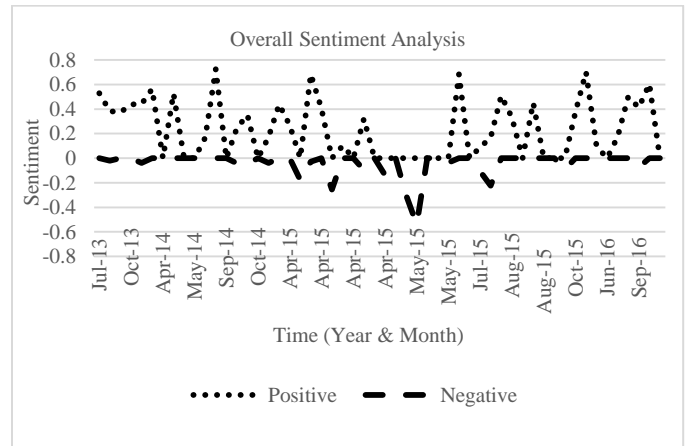


Fig. 3.  Sentiment analysis & Overall sentiment score of Hotel Comfort Suites.

*B. Discussions*

The discussions are twofold. The first is the proposed model and secondly on the valuable insights from the experiments output as in Table VI. These are described below.

*1) Comparison of the proposed model:* The hybrid model evaluation of comparision results can be summarized as:

- The results suggest that the proposed hybrid model is an effective way to perform aspect-based sentiment analysis on hotel reviews.

- Table V shows a comparison of the proposed hybrid model with other state-of-the-art literature. As it can be seen, the proposed model outperforms all other models in terms of precision, recall, and accuracy.

- The hybrid model was able to extract five aspects from hotel reviews: food, location, comfort & facilities, staff, and value for money.

- The hybrid model was able to generate a sentiment score for each aspect of each hotel.

- Overall, this hybrid performed much better than all state-of-the-art literature compared.

*2) Aspects and sentiments-the valuable insight of aspects:* The hybrid model results can be summarized as:

- Table VI shows a comparison of the different aspects of five hotels in the USA. As it can be seen, Fairfield Inn has the highest average sentiment score for location, followed by Little Paradise, Days Inn El Reno, Hawthorn Suites, and Comfort Suites.

- The sentiment scores for each aspect of each hotel can be used by potential guests to choose the hotel that best suits their needs.

- Fig. 2 shows a comparison of the location sentiment scores of the five hotels in the USA over time. As can be seen, Fairfield Inn consistently has the highest location sentiment score.

- Fig. 3 shows a sentiment analysis of Hotel Comfort Suites over time. As can be seen, the overall sentiment score of the hotel is positive.

Overall, the results of the experiment suggest that the proposed hybrid model is an effective way to perform aspect-based sentiment analysis on hotel reviews. The sentiment scores /polarity generated by the model can be used by potential guests to choose the hotel based on aspect that best suits their needs.

## VI. Conclusion and Limitations

In this paper, we propose hybrid model with syntax dependency, lexicon with logistic regression to extract multi aspects and sentiments. By introducing the positional features with syntax dependency to address long dependencies, to deal with multi aspects. We used aspect-based sentiment analysis of the customer reviews with public hotel dataset of US and Europe. The experiment focused on five generalized aspects location, comfort and facilities, staff, food, and value for money. The score of sentiment polarity for aspects in the review is calculated. Finally, for every aspect as mentioned, the mean of the aggregated score of sentiment polarity generated. The experiment results are quite promising and found better in comparison to the state-of-the-art literature. Clearly, the work is able to summarize the sentiment of customer reviews on the four basic aspects. From a business intelligence perspective, knowing about the aspects a hotel offers is crucial. The aggregated outcome will help user to know which hotel is best for which aspect and can decide better. This research offers insightful conclusions on the aspect-based sentiment analysis of hotel reviews. As future work, we shall try to improve experiment result accuracy by using various dataset. The dataset was limited to hotel only in future the other datasets can be explored. We also would replicate this for other aspects like

value for money, weather, etc. and for reviews written in other languages.

## References

[1] Global No.1 Business Data Platform, available on https://www.statista.com/, 1st November 2020.

[2] T. Chen, P. Samaranayake, X. Y. Cen, M. Qi, and Y. C. Lan, "The Impact of Online Reviews on Consumers' Purchasing Decisions: Evidence from an Eye-Tracking Study," Frontiers Psychol., vol. 13, no. June, 2022, doi: 10.3389/fpsyg.2022.865702.

[3] El-Masri, M., Altrabsheh, N., Mansour, H., & Ramsay, A. (2017). A web-based tool for Arabic sentiment analysis. Procedia Computer Science, 117, 38-45.

[4] Wang, G., Zhang, Z., Sun, J., Yang, S., & Larson, C. A. (2015). POS-RS: A Random Subspace method for sentiment classification based on part-of-speech analysis. Information Processing & Management, 51(4), 458-479.

[5] Luo, F., Li, C., & Cao, Z. (2016, May). Affective-feature-based sentiment analysis using SVM classifier. In Computer Supported Cooperative Work in Design (CSCWD), 2016 IEEE 20th International Conference on (pp. 276-281). IEEE.

[6] Goel, A., Gautam, J., & Kumar, S. (2016, October). Real time sentiment analysis of tweets using Naive Bayes. In Next Generation Computing Technologies (NGCT), 2016 2nd International Conference on (pp. 257-261). IEEE.

[7] El Alaoui, I., Gahi, Y., Messoussi, R., Chaabi, Y., Todoskoff, A., & Kobi, A. (2018). A novel adaptable approach for sentiment analysis on big social data. Journal of Big Data, 5(1), 12.

[8] Baydogan, C., & Alatas, B. (2018, March). Sentiment analysis using Konstanz Information Miner in social networks. In Digital Forensic and Security (ISDFS), 2018 6th International Symposium on (pp. 1-5). IEEE.

[9] Ramadhani, A. M., & Goo, H. S. (2017, August). Twitter sentiment analysis using deep learning methods. In Engineering Seminar (InAES), 2017 7th International Annual (pp. 1-4). IEEE.

[10] Swain, A. K., & Cao, R. Q. (2017). Using sentiment analysis to improve supply chain intelligence. Information Systems Frontiers, 1-16.

[11] Khoo CS and Johnkhan SB. Lexicon-based sentiment analysis: comparative evaluation of six sentiment lexicons. J Inf Sci. Epub ahead of print 19 April 2017. DOI: 10.1177/0165551517703514.

[12] Zhang P and He Z. Using data-driven feature enrichment of text representation and ensemble technique for sentence-level polar- ity classification. JInfSci 2015; 41: 531–549.

[13] Onan A and Korukoğ˘ lu S. A feature selection model based on genetic rank aggregation for text sentiment classification. JInf Sci 2017; 43: 25–38.

[14] Martı´n-Valdivia MT, Martı´nez-Ca´mara E, Perea-Ortega JM et al. Sentiment polarity detection in Spanish reviews combining supervised and unsupervised approaches. Expert Syst Appl 2013; 40: 3934–3942.

[15] B. Liu and L. Zhang, (2012). A Survey of Opinion Mining and Sentiment Analysis. Mining Text Data.

[16] Woldemariam, Y. (2016). Sentiment analysis in a cross- media analysis framework. IEEE International Conference on Big Data Analysis (ICBDA).

[17] Luo, F., Li, C., & Cao, Z. (2016). Affective-feature-based sentiment analysis using SVM classifier. IEEE 20th International Conference on Computer Supported Cooperative Work in Design.

[18] J. R. Alharbi and W. S. Alhalabi, "Hybrid approach for sentiment analysis of twitter posts using a dictionary-based approach and fuzzy logic methods: Study case on cloud service providers," Int. J. Semant. Web Inf. Syst., vol. 16, no. 1, pp. 116–145, 2020,

[19] Jime´nez-Zafra SM, Martı´n-Valdivia MT, Martı´nez-Ca´mara E et al. Combining resources to improve unsupervised sentiment analysis at aspect-level. J Inf Sci 2016; 42: 213–229.

[20] Muangon A, Thammaboosadee S and Haruechaiyasak C. A lexiconizing framework of feature-based opinion mining in tourism industry. In: Proceedings of the fourth international conference on digital information and communication technology and it's applications (DICTAP), Bangkok, Thailand, 6–8 May 2014, pp. 169–173. New York: IEEE.

[21] Wang W, Wang H and Song Y. Ranking product aspects through sentiment analysis of online reviews. J Exp Theor Artif In 2017; 29: 227–246.

[22] Marrese-Taylor E, Vela´squez JD and Bravo-Marquez F. Opinion zoom: a modular tool to explore tourism opinions on the web. In: Proceedings of the 2013 IEEE/WIC/ACM international joint conferences on web intelligence (WI) and intelligent agent tech- nologies (IAT), vol.3, Atlanta, GA, 17–20 November 2013, pp.261–264. New York: IEEE.

[23] Marrese-Taylor E, Vela´squez JD and Bravo-Marquez F. A novel deterministic approach for aspect-based opinion mining in tourism products reviews. Expert Sys Appl 2014; 41: 7764–7775.

[24] Afzaal M, Usman M, Fong ACM et al. Fuzzy aspect based opinion classification system for mining tourist reviews. Adv Fuzzy Syst 2016; 2016: 6965725.

[25] Colhon M, Ba˘ dica˘ C and Sxendre A. Relating the opinion holder and the review accuracy in sentiment analysis of tourist reviews. In: Proceedings of the international conference on knowledge science, engineering and management, Melbourne, VIC, Australia, 19–20 August 2014, pp. 246–257. New York: Springer.

[26] Mukherjee A and Liu B. Aspect extraction through semi-supervised modeling. In: Proceedings of the 50th annual meeting of the association for computational linguistics: long papers, vol. 1, Jeju Island, Korea, 8–14 July 2012, pp. 339–348. New York: ACM.

[27] Kayaalp NF, Weckman GR, Ii WAY et al. Extracting customer opinions associated with an aspect by using a heuristic based sentence segmentation approach. Int J Bus Inf Syst 2017; 26: 236–260.

[28] Wu Y and Ester M. Flame: a probabilistic model combining aspect based opinion mining and collaborative filtering. In: Proceedings of the eighth ACM international conference on web search and data mining, Shanghai, China, 2–6 February 2015, pp. 199–208. New York: ACM.

[29] Shams M and Baraani-Dastjerdi A. Enriched LDA (ELDA): combination of latent Dirichlet allocation with word co-occurrence analysis for aspect extraction. Expert Syst Appl 2017; 80: 136–146.

[30] Mubarok MS and Adiwijaya Aldhi MD. Aspect-based sentiment analysis to review products using naı¨ve Bayes. AIP ConfProc 2017; 1867: 020060.

[31] Xu X, Cheng X, Tan S et al. Aspect-level opinion mining of online customer reviews. China Commun 2013; 10: 25–41.

[32] Catal C and Nangir M. A sentiment classification model based on multiple classifiers. Appl Soft Comput 2017; 50: 135–141.

[33] Pontiki M, Galanis D, Papageorgiou H et al. SemEval-2016 task 5: aspect based sentiment analysis. In: Proceedings ofthe 10th international workshop on semantic evaluation (Semeval-2016), San Diego, CA, 16–17 June 2016, pp. 19–30. Stroudsburg, PA: Association for Computational Linguistics.

[34] Pontiki M, Galanis D, Papageorgiou H et al. SemEval-2015 task 12: aspect based sentiment analysis. In: Proceedings ofthe 9th international workshop on semantic evaluation (Semeval-2015), 2015, pp. 486–495, http://alt.qcri.org/semeval2015/task12/

[35] Akhtar MS, Gupta D, Ekbal A et al. Feature selection and ensemble construction: a two-step method for aspect based sentiment analysis. Knowl-Based Syst 2017; 125: 116–135.

[36] Ali F, Kwak KS and Kim YG. Opinion mining based on fuzzy domain ontology and support vector machine: a proposal to auto- mate online review classification. Appl Soft Comput 2016; 47: 235–250.

[37] B. Bansal and S. Srivastava, "Hybrid attribute based sentiment classification of online reviews for consumer intelligence," Appl. Intell., vol. 49, no. 1, pp. 137–149, Jan. 2019, doi: 10.1007/s10489-018-1299-7.

[38] Shoiab A and Ajit D 2015 A novel approach for sentimental analysis and opinion mining based on SentiWordNet using web data Int. Conf. on Trends in Automation, Communications and Computing Technology (India: IEEE Press) pp 1-5.

[39] Alexandra C, Valentin S and Bogdan M 2015 Sentiment analysis from product reviews using SentiWordNet as lexical resource 7th International Conference on Electronics, Computers and Artificial Intelligence (Bucharest, Romania: IEEE Press) pp 1-4.

[40] SentiWordNet",SentiWordNet,2010.http://sentiwordnet.isti.cnr.it/ [Accessed 09 March 2017].

[41] Sindhu Chandra S 2018 Aspect based sentiment analysis of amazon product reviews Int. J of Pure and Applied Mathematics vol 118 pp 151-7.

[42] Barkha B and Sangeet S 2018 Sentiment classification of online consumer reviews using word vector representations Procedia Computer Science: Int. Conf. on Computational Intelligence and Data Science vol 132 (Elsevier) pp 1147–53.

[43] L Santhosh K, Jayanti D and Jharna M 2016 Opinion mining and sentiment analysis on online customer review Int. Conf. on Computational Intelligence and Computing Research (India: IEEE Press) pp 1-4.

[44] Nisha Y, Rajeev K, Bhupesh G and Asif U K 2019 Extraction-based text summarization and sentiment analysis of online reviews using hybrid classification method Sixteenth Int. Conf. on Wireless and Optical Communication Networks (India: IEEE Press)pp1-6.

[45] Kushal B and Durga T 2019 Feature based summarization of customers' reviews of online products Procedia Computer Science: 17th Int. Conf. in Knowledge Based and Intelligent Information and Engineering Systems (Elsevier) pp 142-51.

[46] Wu, C., Xiong, Q., Yi, H., Yu, Y., Zhu, Q., Gao, M., & Chen, J. (2021). Multiple-element joint detection for Aspect-Based Sentiment Analysis. Knowledge-Based Systems, 223, 107073. https://doi.org/10.1016/j.knosys.2021.107073

[47] C. Wu, F. Wu, S. Wu, Z. Yuan, and Y. Huang, "A Hybrid Unsupervised Method for Aspect Term and Opinion Target Extraction," Knowledge-Based Systems, vol. 148, pp. 66-73, 2018

[48] Zainuddin, N., Selamat, A., & Ibrahim, R. (2016). Improving twitter aspect-based sentiment analysis using hybrid approach. In N. T. Nguyen, B. Trawiński, H. Fujita, & T.-P. Hong (Eds.), Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics) (Vol. 9621, pp. 151–160). Springer Berlin Heidelberg.

[49] Md Shad Akhtar, Asif Ekbal, and Pushpak Bhattacharyya. 2016. Aspect based sentiment analysis in Hindi: Resource creation and evaluation. In Proceedings of the 10th Edition of the Language Resources and Evaluation Conference (LREC). 2703–2709.

[50] Hu, M., Liu, B. (2004). Mining and summarizing customer reviews. Proceedings of the Tenth International Conference on Knowledge Discovery and Data Mining.

[51] Zhou, Y., Zhu, F., Song, P., Han, J., Guo, T., & Hu, S. (2021). An Adaptive Hybrid Framework for Cross-domain Aspect-based Sentiment Analysis. Proceedings of the AAAI Conference on Artificial Intelligence, 35(16), 14630–14637.

[52] Accessed on 5 February 2021. https://www.kaggle.com/jiashenliu/515k-hotel-reviews-data-in-europe.

# A Comparative Study of Cloud Data Portability Frameworks for Analyzing Object to NoSQL Database Mapping from ONDM's Perspective

Salil Bharany[1*], Kiranbir Kaur[2], Safaa Eltayeb Mohamed Eltaher[3],
Ashraf Osman Ibrahim[4*], Sandeep Sharma[5], Mohammed Merghany Mohammed Abd Elsalam[6]

Department of Computer Science and Engg, Lovely Professional University, Phagwara , India[1]
Department of Computer Engg. And Technology, Guru Nanak Dev University, Punjab, India[2]
Prince Sattam Bin Abdulaziz University, College of Computer Engineering and Sciences, Department of software engineering[3]
Creative Advanced Machine Intelligence Research Centre, Faculty of Computing and Informatics, Universiti Malaysia Sabah,
88400 Kota Kinabalu, Sabah, Malaysia[4]
Department of Computer Engg. and Technology, Guru Nanak Dev University, Punjab, India[5]
Faculty of Computer Science and Information Technology, Alzaiem Alazhari University, Khartoum North 13311, Sudan[6]

*Abstract*—Cloud computing revolves around storing and retrieving data in a portable manner. However, practical data portability across multiple Database-as-a-service (DBaaS) cloud data stores is challenging. This becomes even more complicated when data needs to be migrated between different types of data storage, such as SQL and NoSQL databases. NoSQL databases have gained significant popularity among developers due to their ability to provide high availability, fault tolerance, and scalability, making them suitable for managing big data in large-scale infrastructures. However, the varied data models in NoSQL databases make it difficult to migrate or port data among data repositories. Object to NoSQL database mappers (ONDMs) solves this problem. However, only a few ONDMs are available for C#.NET development, and the ONDM market used in Java development could be more stable. To address this issue, we propose building a middleware solution using the .NET framework to support cloud data portability, leveraging the capabilities of ONDMs. In this study, we evaluate several frameworks and compare them to our suggested middleware solution through empirical research. Our middleware solution can perform open network data management (ONDM) and object-relational mapping (ORM).

*Keywords—NoSQl; Portability; Cloud; middleware; platform as a service; platform services*

## I. Introduction

Cloud Computing has become a pre-eminent paradigm for hosting modern software systems, and the database layer is the most valuable and extensive layer of a software system [1-2]. The heterogeneity of cloud service providers (CSPs), the data stores they offer, and the software systems pose substantial impedance while developing an approach for cloud data migration. However, the database-related requirements of modern applications call for polyglot persistence [3]. An application that leverages persistent polyglot databases is considerably more arduous to design and implement than an application using just one backend [7]. The overhead of configuration, deployment and maintenance keeps increasing with each DB used. This makes implementing polyglot persistence quite tricky without the detailed know-how of involved DBs.

### A. Data Models

The use of more than one data model within a single system has become a usual practice for modern application development [4]. The cloud computing paradigm supports both of the types of models for data storage:

*1) Relational (SQL) data models:* Relational data models are schema-based, store data in the form of tables, and maintain ACID (Atomicity, Consistency, Isolation, and Durability) properties. They prevailed since the 1970s when E.F Codd proposed they orchestrate the data into tables (or relations) consisting of rows (also known as records/tuples) and columns (also known as attributes). Each table has a unique key called the primary key which identifies each row and may have a foreign key that represents a primary key of some other table for cross-reference [5].

*2) NoSQL data model:* The acrostic for NoSQL means "Not Only SQL" rather than completely against the traditional relational databases (DBs), as is commonly misunderstood. Carl Strozzi1, in 1998 first time, used the term "NoSQL" to name his open-source relational DB "Strozzi NoSQL". This DB used APIs with several plugins and libraries instead of using SQL for accessing the data. NoSQL data stores are distinguished in the following four categories based on data and query models, and persistence design [6]:

*a)* Key-Value DBs represents a model based on keys-values and are easy to implement. These are suitable to store session information, user profiles, or storing shopping cart data. Examples include Redis, Voldemort, Riak.

*b)* Document DBs in which semi-structured documents are stored in JSON format (XML and YAML formats are also supported), are suited for big data storage and better query performance. Examples are MongoDB, Apache CouchDB, and Cosmos DB.

*c)* Column family DBs represent a model for storing and processing huge amounts of data, which is distributed over various machines without rigid consistency. Examples are Apache Cassandra, HBase, and Apache Accumulo.

*d)* Graph DBs which are suitable for storing relationships between entities. Examples are Neo4j, OrientDB, and AllegroGraph.

Each mired data store possesses its specific benefits. Relational DBs are favored if the data to be stored concerns financial transactions, as these DBs abide by transactional properties. On the other hand, the evolution of the Internet, social networking sites, and Cloud Computing has disputed the domination of relational DBs as the only selection of DBMS. Various considerations like prices, the volume of data, and the speed at which the data is being generated as well as consumed, dictate how and where the storage and management of the data.

## II. OBJECT TO NoSQL DATABASE MAPPERS (ONDMS)

A single application may need heterogeneous DBs for the various types of requirements, for example [7]:

- For User Sessions: Redis is best suited for quick access for reads and writes without having to be durable.

- For financial data and reporting: RDBMS (Relational database management system) is required as this kind of data needs transactional updates. Moreover, data would better fit in a tabular structure.

- Product catalog: MongoDB is best as it supports a lot of reads and infrequent writes.

- Analytics and user activity logs: Cassandra can better handle a high volume of writes on multiple nodes.

And there may be many more types of requirements for application data, leading to the selection of appropriate DBs. Therefore, the application may require the simultaneous use of different DBs (relational as well as NoSQL, called Polyglot persistence) on different cloud platforms and also a data migration from one kind of data store to another, of similar type (SQL to another SQL) or dissimilar type (SQL to/from NoSQL). As there is a looming dearth of standardized query languages, it poses an adverse technical lock-in while building applications against the native interfaces of NoSQL data stores [8]. The solution to evade vendor lock-in caused due to selecting a particular database technology is to leverage Object-NoSQL Database Mappers (ONDMs). ONDMs offer a uniform abstraction interface for heterogeneous NoSQLs. ONDM frameworks decouple applications from database specifics and provide data portability [14].

- Handling the conversion of objects to the relational data model and vice versa.

- Managing persistence to the destination DB.

- Providing software developers with a uniform data access interface to store and query objects programmatically.

Our middleware's architectural design is a Repository pattern. Repositories are classes that contain the logic necessary to access data sources. They consolidate common data access functions, improving maintainability and separating database access from the domain model layer. Because of strong typing, the code that must be implemented to use our middleware is simplified. This allows us to concentrate on the business logic rather than the data access plumbing. ONDMs are developer-centric and let the developers carry the application abstractions without having to be cognizant of the database and use these databases without expecting a level of expertise in those [5]. The benefits of using ONDMs include simplifying porting of an application to other NoSQL data stores and database interoperability as well as polyglot persistence [9]. There are ONDMs called Multi Data Store Mappers supporting multiple NoSQL data stores and ONDMs called Single Data Store Mappers supporting only a particular system [10].

- Kundera2: It is a capable JPA-based object-datastore mapping library that greatly cuts down the programming efforts needed to perform CRUD operations on NoSQL data stores.

- Spring Data3: It is an umbrella project that alleviates the use of data access technologies, namely relational and NoSQL, Map Reduce frameworks, as well as cloud-based data services. It provides a Spring-based data access programming model that preserves the special features of the underlying data stores [18].

- DataNucleus4: We also tried another industry-ready ONDM framework, 'Data Nucleus' for the implementation but faced the following difficulties [19].

- Mongo - The library exposed by DataNucleus and JavaMongo lib had clashing classes in the same classpath. This created issues while building the application [20].

- MySQL - Framework was enhancing model classes after running the maven enhancement step, as mentioned in the documentation. Still, it was not able to detect them at the time of attempting to persist the object [23].

So, we dropped DataNucleus for the comparison with our proposed middleware. Our selection of databases to be implemented tried to find the databases that are not only quite prevalent and ripe but also have great applicability in specific fields [22] [24]. MongoDB and Cassandra are the most prominent NoSQL databases in the market. MongoDB produces high throughput, and Cassandra supports horizontal scalability [25]. MongoDB is supported by almost all ONDMs, followed by Cassandra. Our selection of databases tried to find the databases that are not only quite prevalent and ripe but also have great applicability in specific fields [26].

## III. IMPLEMENTATION TECHNOLOGY - .NET CORE

We have created a custom data model based on Twitter data set to benchmark the proposed middleware and the other frameworks. Some of the key features of .NET Core platform are highlighted below.

- The. NET Core is a new version of Microsoft. NET Framework is a free, open-source, general-purpose programming platform. It is a cross-platform framework that works on Windows, macOS, and Linux [28].

- The .NET Core Framework may be used to create a variety of applications such as mobile, desktop, online, cloud, IoT, machine learning, microservices, and so on.

- The .NET Core is developed from the bottom up to be a modular, lightweight, fast, and cross-platform Framework [30]. It offers the essential capabilities necessary to run a basic.NET Core app. Other functionalities are available as NuGet packages, which you may add to your application as needed [30]. As a result, the.NET Core program performs faster, has a smaller memory footprint, and is easier to maintain.

It is a new platform that is gaining traction in the industry, but there are no ONDM frameworks available for it. This is one of the main reasons to opt .NET Core framework for our middleware implementation [31]. Although Microsoft provides its ORM for .NET Core named ENTITY FRAMEWORK, it is strictly an ORM (that means it is only for RDBMS mapping to objects and not for NoSQLs). Table I presents that most of the ONDMs available are for Java language [32] [34]. Although individual NoSQL database drivers [14] or wrappers are available for the C# language, there are no mature ONDM frameworks for C#.

TABLE I.    ONDM FRAMEWORKS SUPPORTED BY DIFFERENT OBJECT-ORIENTED PROGRAMMING LANGUAGES

| OOPL | ONDM Frameworks | Inactive Frameworks |
|---|---|---|
| Java | Apache Gora, Kundera, Data Nucleus, EclipseLink, Eclipse JNoSQL, Spring Data, Hibernate OGM, GORM | Java |
| Python | KEV, pyDAL | NA |
| JavaScript | JS Data | Resourceful |
| Node.JS | Thinodium, Bass, Waterline, JS Data | JugglingDB, Cleverstack, Node Docu- |
| PHP | Lithium, Yii framework, Doctrine | KO3-NoSQL, Vork |
| C#.NET | | Slazure, Charisma |
| Scala | Lift | Activate Framework |

Definitions

- Poly DB: The frameworks support multiple types of database systems (i.e., relational and NoSQL).

- Wrapper: The library is a wrapper around a database system; this means it might not be an object-mapper (e.g. driver). It just interfaces with the application, but it may not have the capability of object mapping [35].

- ODNM: The framework has objected to NoSQL database mapping capabilities.

- Strict OR/NDM: The framework strictly has either ONDM or ORM mapping functionality [36].

OUR proposed middleware [1] is all POLYDB (as it is supporting multiple DBslike SQL Server, MongoDB, and Cassandra) as well as ORM and ONDM.

- Mongo - The library exposed by DataNucleus and JavaMongo lib had clashing classes in the same classpath. This was creating issues while building the application.

- MySQL - Framework was enhancing model classes after running the maven enhancement step, as mentioned in the documentation. Still, it was not able to detect them at the time of attempting to persists the object.

- SpringData - The Challenge was to integrate with the DBs only. Enough documentation is available to make the application ready.

- OBDApi - There was code in the application that was creating issues while building the application. We needed to remove the unnecessary pieces to make it work.

- Kundera SQL - No major challenge apart from integrating with the DB and adding code for our use case. Analyzed the code to identify how it will work.

In the paper [11], the author introduces and defines the term "ONDM (Object-NoSQL Datastore Mapper) is a framework to facilitate the storage and retrieval of persistent objects in NoSQL datastore systems". In [6] it has been studied state-of-the-art ORMs and dedicated ONDMs that are capable of handling disparate NoSQL data stores. This work studies the performance of the abstraction layers for NoSQL data stores with an emphasis on the runtime performance impact. In the paper [9] also, the authors provide a performance evaluation of various ONDM frameworks [9]. The main difference to our work is that we perform a more comprehensive performance evaluation and contemplate with academic frameworks [12] and [13]). Table IV reveals that most of the ONDMs are available for Java language. [14] Although individual NoSQL database drivers or wrappers are available for C# language, there are no mature ONDM frameworks for C#. We compare analytically our proposed middleware with the academic frameworks CDPort and ODBAPI as well as industry-ready ONDMs viz. Kundera and Spring Data. The proposed middleware relieves the user of these saddles of dealing with the specific APIs. All he needs to do is change the connection string in the application configuration file (appsettings.json).

### A. Our Contribution

We offered a middleware solution created in.NET to allow cloud data portability, which corresponded to the capability of ONDMs in terms of performance and functionality. In this study, we compare our suggested middleware solution with the other frameworks and conduct an empirical evaluation of each of the frameworks. This paper demonstrates that our middleware can serve as both an ORM and an ONDM. Some of the core contributions have been mentioned below.

*1)* We discussed various data models used for storing data.

*2)* ONDMs (Object to NoSQL data mappers (Academic and Industrial)) have been also discussed.

*3)* Available ONDMs are mostly developed for Java developers and to the best of us knowledge, no ONDM is available for .NET developers. We developed .NET ONDM in previous paper and validated it by comparing it with other ONDMs (two academic and two industrial).

*4)* The results we got after experimentation proved our middleware have comparable performance with respect to the above said ONDMs.

## IV. RELATED WORK

Data portability has been taken up by researchers in the literature, where it is considered a mechanism that enables the migration of data as well as enhances interoperability across multiple heterogeneous cloud platforms [15]. While working towards data portability among clouds, the requirement of converting one type of database into another rises owing to the numerous types (SQL and NoSQL) and data models (key-value, columnar, document-oriented, and graph) of the databases offered by the providers. One solution is the mapping of objects to NoSQLs which essentially corresponds to the functionality of ODNMs. We have also proposed a solution to support cloud data portability in [1], which maps the objects into cloud NoSQLs (MongoDB and Cassandra). Other solutions include [16]:

- SQL fication of NoSQL databases with SQL-like wrappers which generally provide various features corresponding to those of classical relational database query language while retaining a grammar identical to that of SQL

- Meta-model approaches which abstract from the data models by identifying the common concepts in different NoSQL solutions' data models.

The rivet of the middleware is that the application, the database, and the platform basic services (such as message queues, email, and SMS service) are so loosely coupled that each of these can be ported to any of the clouds (supported by the middleware) without having to rewrite much code in the application. Although a plethora of research efforts has been done towards data portability, our proposed work relates to [12, 13]. To the best of our knowledge, data migration among clouds (where data previously stored in one cloud is shifted/copied to another cloud) is not much covered in the literature. Some notable research works towards data portability are discussed in Table II.

TABLE II. ANALYSIS OF THE RELATED WORK

| Ref. | Solution approach | Work Done |
|------|-------------------|-----------|
| [17] | Design patterns | This paper proposed an effective design pattern method for shifting data from a columnar DB (HBase) to a graph DB (Neo4J) and vice versa. However, this work appears to be only a suggestion, as no implementation work is provided in this or any subsequent publications published by the author (to the best of our knowledge). |
| [18] | Service Delivery Cloud Platform (middleware) and common API | This paper proposed a cloud middleware infrastructure called SDCP and offered a common API to deliver three cloud services viz. Storage, DB, and Notification service. Using JPA (Java Persistence API) methods, they provided abstraction for DB access. |
| [19] | CSAL (Cloud Storage Abstraction Layer) | An abstraction layer is also provided here in order to give common storage abstraction to diverse cloud providers. The layer also creates a namespace that programmers may utilize to support blobs, tables, and queues. |
| [20] | Abstraction layer | This paper presented a mediation-based approach to integrate SQL and NoSQL DBs to retrieve data from either of them. Moreover, their proposed extended SQL can execute join queries as well. |
| [21] | GUI tool, point to point the translator | This thesis work implemented a Graphical User Interface tool that alleviates the data migration from relational DB to NoSQL document data stores. |
| [22] | NoSQLayer | This paper focused on the automatic translation of SQL queries to NoSQL by proposing a framework called "NoSQLayer". The focus here is in query execution rather than data migration. |
| [23] | Middleware, Common interface | This paper described a subset of SQL commands for accessing NoSQL DBs with the help of proposed middleware which uses C# and ANTLR for parsing SQL. |
| [24] | Heuristic-based | This paper presented a 2-phase transformation mechanism from relational DB to HBase. The first phase transformed relational schema to HBase schema, and the second phase expressed the relationships of two schemas as a set of nested schema mappings. |
| [12] | Common data model | This paper focused on the challenge of data portability and proposed a framework called "CDPort" which is equipped with tools for conversion, transformation, and data exchange among disparate data storage models. |
| [25] | Model Transformation | The authors developed a tool called ERWin HAWK for model transformation and accomplishing data migration. Their work reckoned the query characteristics of relational DB, prepared a model transformation algorithm that extracts the ER model and description tags from relational DBs, and based on these model transformations, migrated the data into MongoDB. |
| [26] | Metamodelling approach | This paper proposed SOS (Save Our Systems) tool which provides a uniform Application Programming Interface based on meta-modeling to support heterogeneous NoSQL data stores. |
| [27] | Model-Driven Engineering | This article addressed the issue of data portability and offered a system called "CDPort" that includes tools for data conversion, transformation, and interchange across heterogeneous data storage types. |
| [28] | Model-Driven Engineering | This paper leveraged MDE to harmonize the differences among the storage models of two prominent PaaS namely GAE and Azure. The authors created a DSL (Domain Specific Language) to support portable applications. They also addressed the issue of data portability of the applications. |
| [29] | Data Adapter | This paper proposed a "Data Adapter" system to provide data synchronization which uses both relational and NoSQL DBs at the same time. Their mechanism offered three modes for query in DB: Blocking Transformation mode (BT), Blocking Dump mode (BD mode), Direct access mode (DA mode). |
| [30] | Metamodel (Hegira4Cloud) | This paper proposed an architecture called "Hegira4Cloud" which provides an intermediate metamodel for Columnar DBs especially. The |

| | | |
|---|---|---|
| [31] | Metamodel | authors also focused on the fault tolerance feature of the NoSQL portability of Big Data applications. This dissertation work proposed a metamodel which is used to convert data to different formats via an intermediate state (especially JSON). |
| [32] | MetaModel | This article extracted system knowledge using an ontology called KDM (Knowledge Discovery meta-model) and utilized many pre-defined patterns to help users through the application migration from one cloud platform to another. |
| [33] | Map Reduce framework | This paper proposed a framework called "JackHare" based on Hadoop and HBase which includes an SQL query compiler, JDBC driver as well as MapReduce method to process the unstructured data of NoSQL DB. The data from relational DB as a source is stored on Hadoop and HBase and is processed with SQL queries. |
| [34] | Unified REST API | This paper presented a unified REST API called Open-PaaS-DataBase (ODBAPI) to interact with the different data stores uniformly. |
| [35] | Cloud data patterns | This paper presented pattern-based application refactoring to accomplish the various migration scenarios of data migration and data portability. |

The author in [14] also proposed the common programming interface but the system does not comply with cloud data store specifications as our proposed system does. The reason is that it leverages the XML in conjunction with SQL for modeling the system [15]. CDPort provided a common data model to handle different cloud storage services through a common API whereas, in our middleware, each datastore has its data model which enables it to detect the associated datastore of the user-defined model. While it may seem that a unified data model is better than using different data models for each datastore but when implemented both the approaches are fine and yield similar results. By using different data models, our middleware detects and converts the objects to their associated data store supported queries/models with more precision. We ought to improve on it in terms of implemented clouds and implemented data storage services. Moreover, a thorough examination of the source code depicts that it is prone to SQL injection as it is not using parameterized queries. We are manually implementing the adapters for each database and if there is any change in the API of the database, we must update the adapter manually. But the user using our middleware in his/her application does not need to change the source code to accommodate this update. He/she just needs to update the middleware package in his/her application.

In the paper [13], it includes more latency than our proposed middleware because the REST API server processes the request as follows:

*1)* The user's request goes to the REST API server.

*2)* REST API server processes the request and sends it to the cloud server.

*3)* The cloud server sends the response to the REST API server.

*4)* REST API server sends a response to the user's applicationHowever, in our proposed middleware [1], all the database related services are packaged within the user's application and hosted together with the user's application.

As NoSQLs are further of various types, it is not practical to develop a single query language. So, the proposed solution to this problem is to leverage the middleware to mitigate the requirement of accessing, storing, and migrating the data from and within the implemented DBs. If the proposed middleware is used while developing the cloud application, it extenuates the implementation details of all the supported DBs. The middleware supports homogenous SQL migration between different clouds, homogeneous NoSQL migration between different clouds, heterogeneous SQL to NoSQL migration in the same cloud, heterogeneous SQL to NoSQL migration between different clouds, heterogeneous NoSQL to NoSQL migration in the same cloud, and heterogeneous category NoSQL to NoSQL migration between the different clouds. The factors to be considered for switching the data store and for migrating the data include the heterogeneous categories of the source and target DBs (SQL and NoSQL). Even within the same category, there are different products available e.g., for SQL, there are MySQL and SQL Server and for document DB, there are MongoDB and Cassandra. NoSQLs further have another level of categorization as briefly discussed in previous section "Object to NoSQL Database Mappers (ONDMs)".

## V. The Proposed Middleware

Cloud portability is defined by [36] as "the ability of data and application components to be easily moved and reused regardless of the choice of cloud provider, operating system, storage format or APIs." Out of the categorized scenarios for cloud portability suggested in [37], only the third and fourth categories have been considered by the proposed middleware and this paper describes the benchmarking of the fourth category particularly.

- Virtual machine portability across cloud providers.
- Portability of virtual machines across cloud providers.
- Portability of applications in the context of Infrastructure as a Service (IaaS).
- Portability of PaaS apps.
- Data portability between cloud providers.

All the entities of the user models are stored as objects. To persist these objects in the appropriate data-store, the object's type is determined with the help of reflection (feature of C# language). A user-defined model is a class that inherits from a particular middleware meta-model base class (as we implemented a separate middleware meta-model corresponding to each type of the supported data store). Fig. 1 shows the decision making about the data store to be used by checking the middleware's meta-model class:
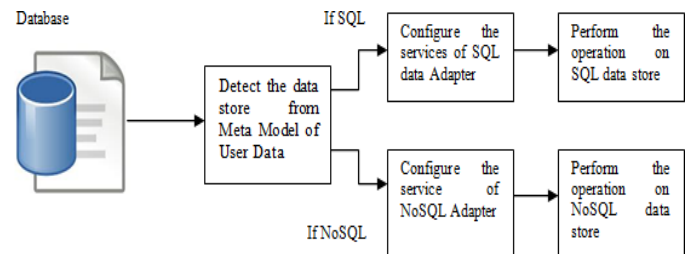


Fig. 1. Decision making procedure to select a data store for persistence.
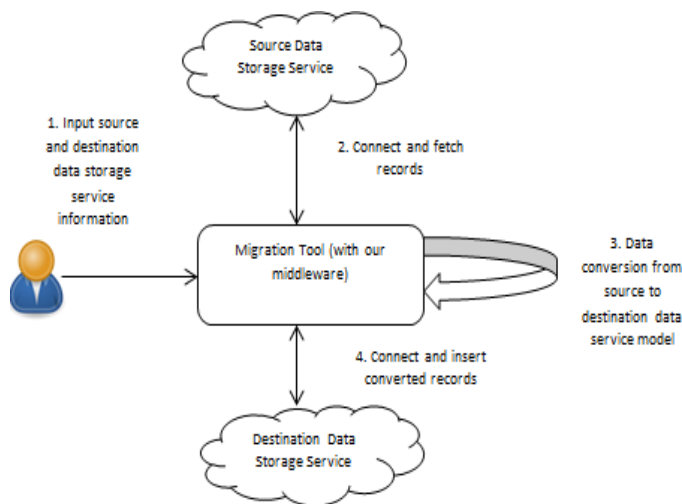
Fig. 2. Data transformation process of the middleware.

The middleware is designed to be extended to support other data stores also. Fig. 2 shows the data transformation process of the proposed middleware where the migration tool takes source and destination data storage service information as an input [37]. Then the connection with the source storage service is established to fetch the records and the tool converts the data from the source to the destination data model [38]. This converted data is inserted into the destination data storage service. A detailed description of the middleware implementation is given in [39]. It was observed that leveraging the middleware makes it quite easy for the user to achieve the data portability decreasing user's efforts greatly [40]. We have experimentally evaluated the industry ready ONDMs namely KUNDERA and Spring Data as well as academic ODNMs namely CDPort and ODBAPI against SQL and NoSQL (MongoDB and Cassandr data-stores [40]. The four candidate methodologies have been evaluated using Twitter dataset and implementing different migration scenarios. An experiment was carried out in the next section to determine the effectiveness of the migration [39]. During the assessment, three cloud platforms were employed (Google Cloud Platform, Microsoft Azure, and Amazon Web Services) [41] [42]. It is also claimed that the suggested middleware is interoperable with various PaaS providers.

## VI. RESULTS AND EVALUATION

We compare our proposed middleware analytically with the academic frameworks viz. CDPort and ODBAPI as well as industry ready ONDMs viz. Kundera and Spring Data. We created a custom data model based on the Twitter data set to benchmark the proposed middleware and the other frameworks. We created two similar applications, one in Java language (to evaluate ODBAPI, Kundera, CDPort, and Spring Data) and another in C#.NET (to evaluate our middleware). Both these applications have minimal functionality to perform just the CRUD operations on the Twitter data set. The time taken to perform these operations using the applications is noted, and these values of readings are compared to know the efficiency of each of them. The experiments were executed on a system with configurations - 2 core machines with 4 GB RAM. The data in Table III was captured for three different

workloads of 1000, 5000, and 10000 no. of tweets/records. In this paper we are using three types of scenarios mentioned below.

Three scenarios are:

1) SQL to/from NoSQL
2) One category of NoSQL to another category NoSQL
3) Even among different SQL data-stores or data stores of the same category NoSQL

In each experiment scenario, the following operations were performed on SpringData, Kundera, ODBAPI and CDPort:

1) Add records (tweets/records)
2) Get all records (tweets/records)
3) Update records (tweets/records)
4) Delete records (tweets/records)

- SpringData It is an enterprise-level ORM with solid developer support and easy integration. SpringData removes all DAO (Data Access Object) implementations. Only the DAO's interface must be defined explicitly. By extending the interface, we obtain all the normal DAO CRUD functions. This informs Spring Data to look for this interface and generate an implementation for it. The problem with Spring Data was merely integrating with DBs [43].

- Kundera - is a "Polyglot Object Mapper"(Single Application Using Multiple Data Storage Technologies) with a JPA interfaces [44]. It serves as a JPA Compliant mapping solution for NoSQL Datastores. After running our scenario, we observed that "Get All" for a lower number of records took more time as compared to "Get All" for a larger number of record [45] (we ran this scenario multiple times to conclude this).

- ODBAPI - This ORM is a unified REST-based API. This API enables to execute CRUD operations on re-lational and NoSQL data stores. There is no support for Cassandra, so we ran our scenario for MySQL and mongo [46]. There was code in the application that was creating issues while building the application, removed the conflicting code to make it work. For SpringData, Kundera, and OBDApi, we ran our scenario by connecting our test application with local DB instances. This helped us by realistically compare the framework performance by not considering network latencies (as compared to if integrated with Cloud DB).

- CDPort - The CDPort's API has been designed to hide the programmatic difference between the different SQL and NoSQL database systems [47]. It enables software developers to easily change their backend cloud-based data storage without the need to change the software code. They expose adapters for each cloud DB and thus client applications need to integrate with these adapters [48]. Thus, providing a clean way to integrate. It provides support for cloud DB. Thus, we have executed our scenario for Amazon RDS and MongoDB (Amazon Document DB) [49].

TABLE III.    COMPARISON OF TIME TAKEN TO PERFORM DATABASE OPERATIONS BY THE MIDDLEWARE VS. OTHER FRAMEWORKS

| Databases & Operations Performed | Proposed Middleware (milliseconds) | | | KUNDERA (milliseconds) | | | ODBAPI (milliseconds) | | | Spring Data (milliseconds) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SQL | 1000 | 5000 | 10000 | 1000 | 5000 | 10000 | 1000 | 5000 | 10000 | 1000 | 5000 | 10000 |
| INSERT | 2442 | 11208 | 20056 | 1310 | 4666 | 8458 | 392 | 1539 | 3536 | 3805 | 53203 | 189860 |
| SELECT | 34 | 175 | 281 | 413 | 72 | 86 | 7 | 29 | 37 | 10 | 177 | 76 |
| UP- DATE | 3060 | 16529 | 29047 | 2594 | 8081 | 14867 | 437 | 2087 | 4724 | 4794 | 88932 | 334545 |
| DELETE | 941 | 4630 | 9581 | 1315 | 4762 | 9359 | 533 | 1666 | 3334 | 3183 | 52341 | 178737 |
| MONGO | | | | | | | | | | | | |
| INSERT | 28 | 320 | 317 | 891 | 1238 | 2299 | 547 | 2000 | 3089 | 701 | 1995 | 4880 |
| SELECT | 33 | 74 | 132 | 487 | 36 | 71 | 19 | 83 | 237 | 82 | 131 | 229 |
| UP- DATE | 70 | 324 | 649 | 2709 | 7204 | 1397 | 821 | 13927 | 51926 | 525 | 1861 | 4116 |
| DELETE | 35 | 172 | 357 | 789 | 2966 | 5820 | 809 | 11624 | 42935 | 384 | 1551 | 3166 |
| Cassandra | | | | | | | | | | | | |
| INSERT | 149 | 647 | 1069 | 1220 | 2899 | 5835 | - | - | - | 1221 | 3640 | 5853 |
| SELECT | 2 | 3 | 4 | 332 | 143 | 192 | - | - | - | 413 | 1105 | 1981 |
| UPDATE | 1537 | 1813 | 2369 | 807 | 2021 | 3298 | - | - | - | 1405 | 2893 | 6423 |
| DELETE | 1241 | 1433 | 1963 | 672 | 1880 | 3499 | - | - | – | 797 | 2004 | 3931 |

For SQL databases, ODBAPI performed the best of all the frameworks which can be seen in readings of Table III and graph of Fig. 3. For the Cassandra database, INSERT and SELECT operations took the least time with our middleware [1], and UPDATE and DELETE operations took comparable time which can be seen in Fig. 4. The middleware proposed in this work can be considered as comparable to the two-industry ready ONDMs (Kundera and Spring Data) and academic framework (ODBAPI) [50]. For the Mongo database, our proposed framework performed exceptionally well as seen in Fig. 5. Comparison between different middleware can be seen in Table III. The data in Table IV was captured for three different workloads of 1000, 5000, and 10000 no. of tweets/records.

As the proposed middleware supports cloud data portability, another comparison is done with the CDPort framework which also supports cloud data portability. Except for the SQL INSERT operation, all other operations took lesser time with our middleware.

TABLE IV.    COMPARISON OF TIME TAKEN USSING DIFFERENT WORKLOADS

| AWS cloud | Proposed Middleware | | |
|---|---|---|---|
| SQL | 1000 | 5000 | 10000 |
| INSERT | 84577 | 452959 | 957680 |
| SELECT | 309 | 1180 | 2999 |
| UPDATE | 111278 | 499048 | 913818 |
| DELETE | 80317 | 440182 | 718930 |
| INSERT | 1361 | 6840 | 14290 |
| SELECT | 1300 | 4767 | 11549 |
| UPDATE | 1648 | 11002 | 13954 |
| DELETE | 680 | 3611 | 7982 |



Fig. 4. Comparison of performance of frameworks for Cassandra CRUD operations on 1000 tweets.

The evaluation included performing CRUD operations on the Twitter data set with different workloads viz. 1000, 5000, and 10000 tweet/records through the proposed middleware, KUNDERA, Spring Data, ODBAPI, and CDPort frameworks as seen in reading of Table V. The total time taken to perform these operations were compared which depicted that middleware performs at par to all these frameworks [40] as can be seen in Fig. 6 and Fig. 7. We created two similar



Fig. 3. Comparison of performance of frameworks for SQL CRUD operations on 1000 tweets.

applications, one in Java language (to evaluate ODBAPI, KUNDERA, CDPort, and Spring Data) and another in C#.NET (to evaluate our middleware). Both these applications have minimal functionality to perform just the CRUD operations on the Twitter data set. The time taken to perform these operations using the application is noted, and these values of readings are compared to know the efficiency of each of them [45-46]. We evaluated the impact of the ODNMs based on application runtime performance as response time is very crucial for the users' experience in the interactive modern applications. Also, different ONDMs have different runtime performance. Although adding ONDMs adds to the performance overhead [1], these provide the benefit of easy portability across disparate NoSQLs [38-43]. For Document DB, our middleware performed much better than CDPort which can be seen in Table IV.
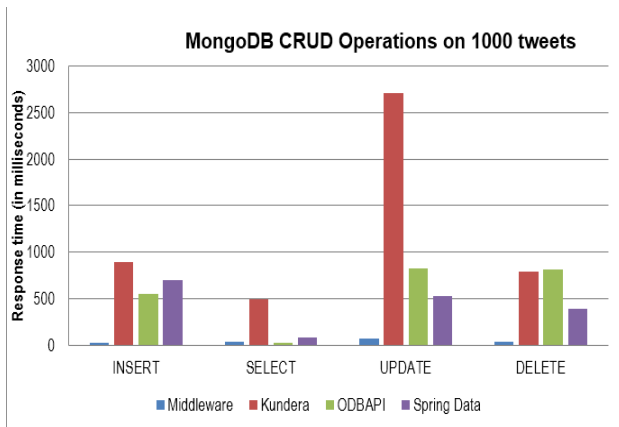


Fig. 5. Comparison of performance of frameworks for MongoDB CRUD operations on 1000 tweets.
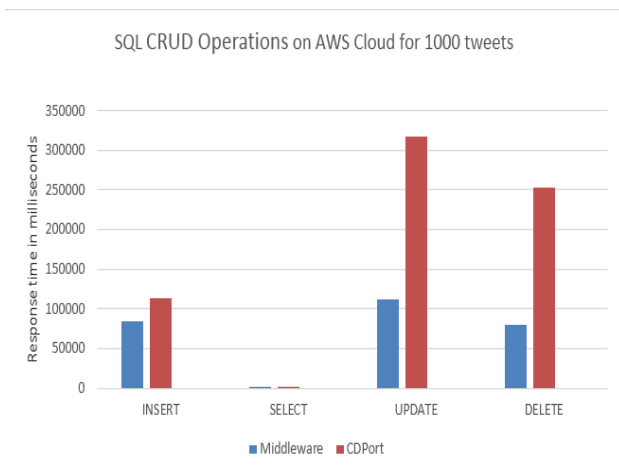


Fig. 6. SQL CRUD Operations on AWS.
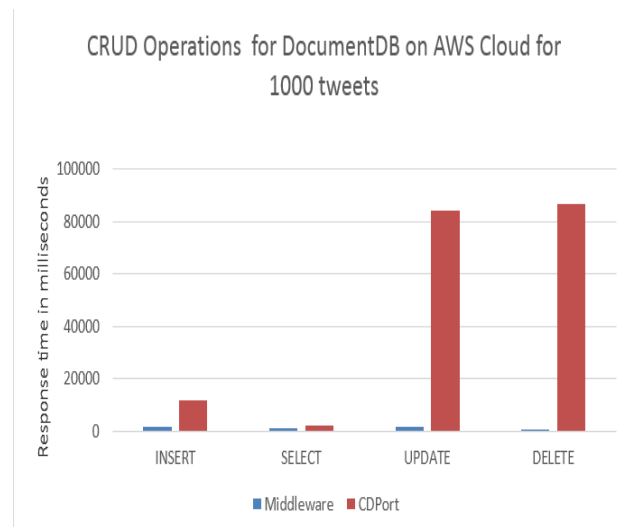


Fig. 7. CRUD operations for document DB.

TABLE V. COMPARISON WITH CDPORT

| AWS cloud | CD Port | | |
|---|---|---|---|
| SQL | 1000 | 5000 | 10000 |
| INSERT | 13939 | 139678 | 183158 |
| SELECT | 568 | 2886 | 4356 |
| UPDATE | 316903 | 1602408 | 2312081 |
| DELETE | 253408 | 1298309 | 1772904 |
| INSERT | 11648 | 12242 | 113997 |
| SELECT | 2032 | 9426 | 19406 |
| UPDATE | 83975 | 409502 | 972376 |
| DELETE | 86491 | 638225 | 982814 |

## VII. CONCLUSION AND FUTURE SCOPE

Compared to an application that only uses a SQL database, a combination of the graph, document, and column-based data stores will have a data access layer that is far more complicated and will require additional work. The developer's knowledge and experience are the primary factors that should be considered when selecting an application's database management system (DBMS). The vast majority of cloud service providers make available various services and application programming interfaces (APIs) that may be used to access and manage the services they offer. A problem with interoperability arises due to the variety of cloud services. Utilizing an intermediary abstraction layer or adhering to pre-existing standards is the recommended action for resolving this problem. This article focuses solely on the database migration process, utilizing a method known as "Object to NoSQL database mappers. Organizations may require transferring the system (software and database layer) among different providers. However, this article only discusses database migration (ONDMs). Evaluation of the effect of the proposed solution's implementation on response time and throughput is used to validate the solution's performance. In addition, the performance is evaluated in relation to other methods described in the published research and commercial solutions currently on the market. According to the findings, our strategy performs noticeably better than the other strategies. The work that will be done in the future will

involve adding support for more clouds and additional data stores that fall into other categories, such as graph and key-value stores.

## REFERENCES

[1] Kaur, S. Sharma, and K.S. Kahlon, "A middleware for polyglot persistence and data portability of big data paas cloud applications", *Computers, Materials & Continua*, vol. 65, no. 2, pp. 1625-1647, 2020

[2] M.H. Ellison, "Evaluating Cloud Migration Options for Relational Databases", 2017

[3] M. Schaarschmidt, F. Gessert, N. Ritter, "Towards automated polyglot persistence", in *Proc. Lect. Notes LNI), Proc. - Ser. Gesellschaft Fur Inform*, 241 ,73–82, 2015.

[4] J. Castrejón, G. Vargas-Solar, C. Collet and R. Lozano, "ExSchema: Discovering and maintaining schemas from polyglot persistence applications", in *Proc. IEEE Int. Conf. Softw. Maintenance,*Eindhoven, Netherlands, pp. 496–499, 2013.

[5] V. Abramova, and J. Bernardino, "NoSQL Databases: MongoDB vs Cassandra", In: Proc. *Int. Conf. Comput. Sci. Softw. Eng. ACM*, Porto, Portugal, pp. 14–22, 2013.

[6] U. Störl, M. Klettke, T. Hauf, S. Scherzinger, and Schemaless "NoSQL data stores - Object-NoSQL mappers to the rescue?", *in Proc. Lect. Notes Informatics (LNI), Proc. - Ser. Gesellschaft Fur Inform*, Bonn Gesellschaft für Informatik ,vol. 241, pp. 579–599, 2015.

[7] M. Fowler, and P. Sadalage, "The future is : NoSQL Databases", 2012.

[8] S. Bharany, S. Sharma, N. Alsharabi, E. Tag Eldin, and N. A. Ghamry, "Energy-efficient clustering protocol for underwater wireless sensor networks using optimized glowworm swarm optimization," *Frontiers in Marine Science, Frontiers Media SA*, *vol. 10*, 2023.

[9] V. Reniers, A. Rafique, D. Van Landuyt, and W. Joosen, "Object-NoSQL Database Mappers : a benchmark study on the performance overhead", *J. Internet Serv. Appl.* vol. 8, pp. 1–16, 2017.

[10] J. R. Lourenço, B. Cabral, P. Carreiro, M. Vieira, and J. Bernardino, "Choosing the right NoSQL database for the job: a quality attribute evaluation", *J. Big Data*., vol. 2, pp. 1–26, 2015.

[11] Reniers, V., Rafique, A., Van Landuyt, D. et al. Object-NoSQL Database Mappers: a benchmark study on the performance overhead. J Internet Serv Appl 8, 1 (2017). https://doi.org/10.1186/s13174-016-0052-x

[12] E. Alomari, A. Barnawi, and S. Sakr, "CDPort: A Portability Framework for NoSQL Datastores", *Arab. J. Sci. Eng*., vol. 40, pp. 2531–2553, 2015.

[13] R. Sellami, S. Bhiri, and B. Defude, "ODBAPI: A unified REST API for relational and NoSQL data stores", *in Proc. - 2014 IEEE Int. Congr. Big Data, BigData Congr*, Anchorage, AK, USA ,pp. 653–660, 2014.

[14] V. Reniers, D. Van Landuyt, A. Rafique, and W. Joosen, "Object to NoSQL Database Mappers ( ONDM ): A systematic survey and comparison of frameworks", *Inf. Syst*, vol. 85, pp. 1–20, 2015.

[15] A. Bansel, "Cloud based NoSQL Data Migration Framework to achieve data portability", *National College of Ireland, Dublin, Ireland*, 2015.

[16] F. Arcidiacono, "Avoiding CRUD operations lock-in in NoSQL databases: extension of the CPIM library", *Politecnico di Milano Computer*, 2015.

[17] M. N. Shirazi, H.C. Kuan, H. Dolatabadi, "Design patterns to enable data portability between clouds' databases", *in Proc ICCSA ,* Salvador, Brazil ,pp.117–120 ,2012.

[18] L.A. Bastião Silva, C. Costa, J.L. Oliveira, A common API for delivering services over multi-vendor cloud resources, J. Syst. Softw. 86 ,2309–2317,2013.

[19] Z. Hill, M. Humphrey, CSAL: A cloud storage abstraction layer to enable portable cloud applications, *in Proc IEEE Int. Conf. Cloud Comput. Technol. Sci. CloudCom ,* Indianapolis, IN, USA ,pp. 504–511. 2010.

[20] S. Bharany et al., "Energy efficient fault tolerance techniques in green cloud computing: A systematic survey and taxonomy," Sustainable Energy Technologies and Assessments, vol. 53. Elsevier BV, p. 102613, Oct. 2022. doi: 10.1016/j.seta.2022.102613.

[21] M. Mughees, Data Migration From Standard SQL to NoSQL, 2013.

[22] L. Rocha, F. Vale, E. Cirilo, D. Barbosa, F. Mourão, A framework for migrating relational datasets to NoSQL, *Procedia Comput. Sci*. 51, 2593–2602, 2015 .

[23] J. Rith, P.S. Lehmayr, K. Meyer-Wegener, Speaking in tongues: SQL access to NoSQL systems, *in Proc. ACM Symp. Appl. Comput. , New York, NY, USA* , pp. 855–857,2014.

[24] C. Li, Transforming relational database into HBase: A case study, *in Proc. 2010 IEEE Int. Conf. Softw. Eng. Serv. Sci. ICSESS*, Beijing, China, 683–687, 2010.

[25] T. Jia, X. Zhao, Z. Wang, D. Gong, G. Ding, Model transformation and data migration from relational database to MongoDB, in Proc. IEEE Int. Congr. Big Data, BigData Congr , San Francisco, CA, USA ,60–67 ,2016.

[26] P. Atzeni, F. Bugiotti, L. Rossi, Uniform access to non-relational database systems: in Proc. The SOS platform, Lect. Notes Comput. Sci , Berlin, Heidelberg.160–174 , 2012.

[27] A. Beslic, R. Bendraou, J. Sopena, J.Y. Rigolet, Towards a solution avoiding vendor lock-in to enable migration between cloud platforms, in Proc CEUR Workshop , MIAMI, FLORIDA, USA 1118 , 5–14, 2013.

[28] E.A.N. Da Silva, D. Lucrédio, A. Moreira, R. Fortes, Supporting multiple persistence models for PaaS applications using MDE: Issues on cloud portability, in *Proc. CLOSER* , Lisbon, Portugal, 331–342 ,2015 ,

[29] S. Bharany, S. Sharma, N. Alsharabi, E. Tag Eldin, and N. A. Ghamry, "Energy-efficient clustering protocol for underwater wireless sensor networks using optimized glowworm swarm optimization," Frontiers in Marine Science, vol. 10. Frontiers Media SA, Feb. 02, 2023. doi: 10.3389/fmars.2023.1117787.

[30] M. Scavuzzo, D.A. Tamburri, E. Di Nitto, Providing big data applications with fault-tolerant data migration across heterogeneous NoSQL databases, in *Proc.BIGDSE* , Austin, TX, USA ,26–32 ,2016.

[31] Curitiba, Data Migration between different data models of NoSql Databases, 2017.

[32] A. Bansel, H. Gonzalez-Velez, A.E. Chis, Cloud-Based NoSQL Data Migration, in *Proc*. Euromicro Int. Conf. Parallel, *Distrib. Network-Based Process ,* , Heraklion, Greece ,224–231, 2016.

[33] W. C. Chung, H.P. Lin, S.C. Chen, M.F. Jiang, Y.C. Chung, JackHare: a framework for SQL to NoSQL translation using MapReduce*, Autom. Softw. Eng.* ,489–508, 2014 .

[34] R. Sellami, S. Bhiri, B. Defude, Supporting Multi Data Stores Applications in Cloud Environments, *IEEE Trans. Serv. Comput* ,59–71,2016.

[35] S. Strauch, V. Andrikopoulos, T. Bachmann, F. Leymann, Migrating application data to the Cloud using Cloud data patterns, in *Proc.* CLOSER , Aachen, Germany 36–46 ,2013.

[36] Z. Zhang, C. Wu, and D. W. L. Cheung, "A survey on cloud interoperability," ACM SIGMETRICS Performance Evaluation Review, *Association for Computing Machinery* , vol. 40, no. 4. pp. 13–22, 2013.

[37] G. C. Silva, L. M. Rose, and R. Calinescu, "Towards a Model-Driven Solution to the Vendor Lock-In Problem in Cloud Computing," in *Proc.International Conference on Cloud Computing Technology and Science.* IEEE, 2013. Bristol, UK, pp. 711-716, 2013.

[38] S. Bjeladinovic, "A fresh approach for hybrid SQL/NoSQL database design based on data structuredness," *Enterprise Information Systems*, vol. 12, no. 8–9 ,pp. 1202–1220, 2018.

[39] Ilin, D., & Nikulchev, E.V. Performance Analysis of Software with a Variant NoSQL Data Schemes. In *Proc. MLSD*, 1-5,2020. Moscow, Russia, 2020, pp. 1-5,

[40] A. AGGOUNE and M. S. NAMOUNE, "A Method for Transforming Object-relational to Document-oriented Databases," in *Proc. ICMIT. IEEE*, 2020. Adrar, Algeria, 2020, pp. 154-158,

[41] M. Li, J. Xu, and L. Han, "Multi-dimensional Analysis of Industrial Big Data Based JSON Document," in *Proc.IEEE Intl Conf on Parallel and Distributed Processing with Applications.IEEE*, Exeter, United Kingdom, ,1066-1073, 2020/

[44] Bharany, K. Kaur, S. Badotra, S. Rani, Kavita, M. Wozniak, J. Shafi, and M. F. Ijaz, "Efficient Middleware for the Portability of PaaS Services

Consuming Applications among Heterogeneous Clouds," *Sensors*, vol. 22, no. 13. MDPI AG, p. 5013, 2022.

[45] Nurhadi, R. B. A. Kadir, and E. S. B. M. Surin, "Evaluation of NoSQL Databases Features and Capabilities for Smart City Data Lake Management," in *Proc. Lecture Notes in Electrical Engineering. Springer Singapore*, South korea, pp. 383–392, 2021

[46] K. Kaur, S. Sharma, and K. S. Kahlon, "Towards a Model-Driven Framework for Data and Application Portability in PaaS Clouds," in *Proc. First International Conference on Sustainable Technologies for Computational Intelligence. Springer Singapore,* pp. 91–105, 2019.

[47] K. Kaur, S. Bharany, S. Badotra, K. Aggarwal, A. Nayyar, and S. Sharma, "Energy-efficient polyglot persistence database live migration

among heterogeneous clouds," *The Journal of Supercomputing*, vol. 79, no. 1. Springer Science and Business Media LLC, pp. 265–294, 2022.

[48] Y.T. Liao, J. Zhou, C.H. Lu, S.C. Chen, C.H. Hsu, W. Chen, M.F. Jiang, Y.C. Chung, Data adapter for querying and transformation between SQL and NoSQL database, Futur. Gener. Comput. Syst. 65, 111–121,2016.

[49] E. M. Onyema et al., "A Security Policy Protocol for Detection and Prevention of Internet Control Message Protocol Attacks in Software Defined Networks," Sustainability, vol. 14, no. 19. MDPI AG, p. 11950, Sep. 22, 2022

[50] J. Roijackers, H.L.G. Fletcher, XML Query Processing: On Bridging Relational and Document-Centric Data Stores*, in Proc*. *LNCS*  , Berlin, Heidelberg, pp. 135–148, 2013.

# Analysis and Application of Antibacterial Drug Resistance Based on Deep Learning

Wei Zhang[1], Yanhua Zhang[2], Qiang Zhang[3], Caixia Xie[4], Yan Chen[5], Jingwei Lei[6*]

Department of Basic Medicine, Zhengzhou Health Vocational College, Zhengzhou 450122, China[1]
Department of Public Education, Zhengzhou Health Vocational College, Zhengzhou 450122, China[2]
Department of Criminal Science and Technology, Henan Police College, Zhengzhou 450046, China[3]
Henan Engineering Research Center for Quality Control and Evaluation of Traditional Chinese Medicine,
School of Pharmacy, Henan University of Chinese Medicine, Zhengzhou 450046, China[4, 6]
Department of Clinical Laboratory, Henan Infectious Disease Hospital, Zhengzhou 450052, China[5]

*Abstract*—The continuous improvement of deep learning technology has led to its deeper application in related fields, especially in the detection of antimicrobial resistance in the medical field. In drug resistance detection, the CNN-ATT-TChan model based on the fusion of CNN algorithm and attention mechanism can classify and organize a large amount of antimicrobial resistance data, achieving standardized processing. Based on mature chemical analysis and testing methods, drug resistance test data was obtained, and the training duration and classification accuracy *F* of the model were discussed in combination with the test data. At the same time, based on relevant research literature, the changes in *ROC* curves and *AUC* values between different models were compared. The results showed that the CNN algorithm using fusion attention mechanism can improve the training time of the model and also improve the classification accuracy of the model. Therefore, the application of CNN-ATT-TChan model combined with attention mechanism in the detection of antimicrobial resistance provides more support for the development of antimicrobial resistance testing.

*Keywords*—*Deep learning; antibacterial drug; CCN algorithm; pharmaceutical chemical analysis; drug resistance testing*

## I. INTRODUCTION

The development of antibiotics, especially antibiotics, has greatly reduced the incidence rate and mortality of many infectious diseases. However, with the continuous use of antibiotics, bacteria can develop resistance to antibiotics, which has become one of the main challenges threatening global public health. Antibiotic resistance refers to the ability of bacteria to resist or become tolerant to chemotherapy agents, antimicrobial agents, or antibiotics. This tolerance may be achieved through gene mutations or exogenous DNA in the transmission of R-factors. Bacteria that are resistant to multiple antibiotics are also known as multidrug-resistant, while bacteria that are considered to be extensively or completely resistant are referred to as super bacteria [1-2]. Resistance generally occurs when many infectious bacteria gradually adapt to first-line or even second-line antibiotics and develop bacterial resistance in the context of antibiotic abuse and overuse. This type of problem poses a huge burden and impact on medical hygiene, veterinarians, agriculture, and society. Affected by drug resistance, treatment plans may be limited or unavailable, posing a higher risk of death, longer hospital stays, and recovery processes for patients, sometimes even leading to long-term incapacity. Therefore, it is necessary to fully analyze the internal reasons for the formation and development of antimicrobial resistance, and based on this, study the role of antimicrobial resistance as shown in Fig. 1. The process of antibiotic resistance occurrence is presented from the perspective of drug resistance gene transfer.
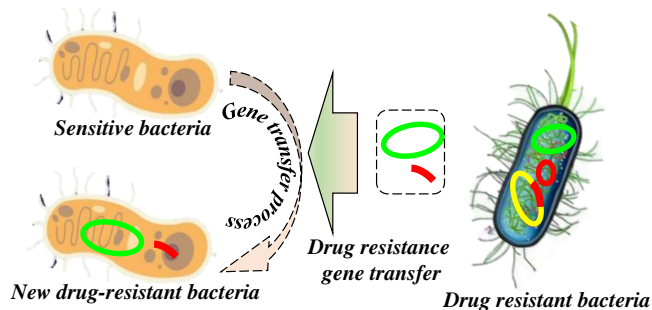


Fig. 1. Process of antibiotic resistance occurrence.

Antimicrobial resistance analysis is a complex process, and deep learning, as one of the key core technologies of big data analysis, provides more means for the improvement and development of antimicrobial resistance analysis. At present, the basic data in the medical field is complex, and electronic medical records, diagnosis and treatment data, laboratory and inspection data, as well as various management data, have become major issues faced by drug resistance analysis. Therefore, further improving the intelligent analysis and processing technology of antimicrobial resistance in the medical field has become a key link in drug detection in this field [3-4]. In the medical field, although there are already many chemical testing methods such as drug resistance test kits and analysis software being applied, with the continuous improvement of data utilization and analysis requirements, relying solely on traditional chemical testing methods cannot provide better support for drug resistance analysis in the in the medical field. The use of antibacterial drugs is mainly determined based on experience and habits, resulting in a lack of comprehensive analysis of the indications and contraindications of antibacterial drugs, as well as the personal characteristics of patients, and the inability to achieve the best expected treatment effect.

In the medical field, traditional bacterial culture methods are often used for drug resistance testing, which takes at least 3-5 days from identifying bacteria to completing drug sensitivity testing [5]. This traditional testing method delays the optimal time for doctors to analyze patients' antimicrobial resistance, posing challenges and difficulties for clinical drug use. At present, there is relatively little research on data analysis and processing of antibacterial drugs based on deep learning algorithms. Researchers have used the XGBoost algorithm of machine learning to construct MIC prediction models between the genome of non-Salmonella typhimurium and multiple antibiotics. Some scholars have also conducted exploratory research on the rational use of antibiotics using machine learning immune genetic algorithms and deep learning short-term memory network models [6-8]. Based on deep learning algorithms and combined with modern chemical methods, it provides a more accurate and efficient means for the analysis of antimicrobial resistance in the medical field. At the same time, it can significantly shorten the testing cycle and provide testing results in a timelier manner [9-10]. Chemical methods play an important role in drug analysis and research and development. Through their diverse analytical methods, from molecular structure to compound labeling, from component testing to local drug analysis, this method provides an effective way to solve drug analysis problems. In the field of medicine, the updates in deep learning technology and the development of chemical methods have provided more comprehensive analytical methods for the analysis of antimicrobial resistance.

This article combines the convolutional neural network (CNN) algorithm in deep learning and proposes a dual channel CNN terminal model in the medical field that integrates attention mechanisms based on the analysis and summary of completed drug resistance experimental data. Using a CNN model for feature extraction and completing self-learning, assigning different weights to information of different importance, and constructing a classification model between testing samples and antibacterial drugs. Using this model to determine the tolerance level of the test samples to antibiotics can provide auxiliary effects for the rational use of antibiotics in the medical field. At the same time, doctors in Harbin can provide the most suitable decision support for individual patients in clinical medication.

## II. ANALYSIS OF DRUG RESISTANCE IN THE CONTEXT OF DEEP LEARNING

### A. Analysis of Deep Learning Algorithms

Deep learning is an important branch of machine learning. By learning deep nonlinear network structures, deep learning trains features layer by layer, gradually transforming the feature representation of samples in the original space into a new feature space, demonstrating the powerful ability to learn the essential features of datasets from the sample set. The biggest advantage of deep learning is that it can automatically learn features and achieve the abstraction process of features. It adopts multi-layer complex structures or multiple layers composed of multiple nonlinear transformations for data processing. The use of deep learning for drug resistance testing and analysis in the medical field has unique advantages.

It can fully explore the deep relationships hidden in a large amount of medical data, obtain more abstract feature values through learning neural networks, and improve the feasibility and accuracy of antimicrobial resistance analysis in the medical field [11-12]. As shown in Fig. 2, a schematic diagram of the network structure of the deep learning algorithm is provided. The algorithm consists of three dimensions: input layer, hidden layer, and output layer, with relevant nodes processing and analyzing data in each layer.
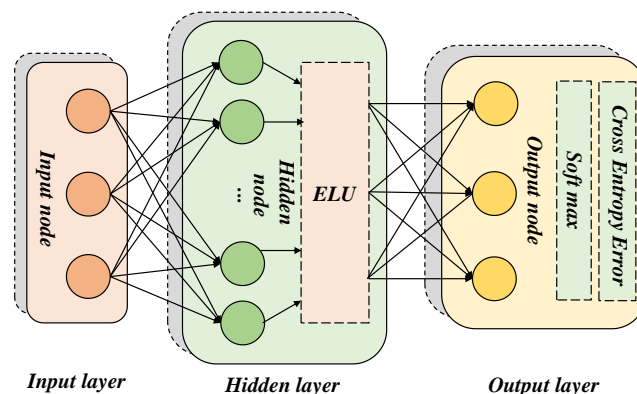


Fig. 2. Schematic diagram of deep learning algorithm network structure.

### B. Application Status of Deep Learning Algorithms in Drug Resistance Testing

The continuous development of deep learning algorithms has led to the application of more and more technologies in the medical field, promoting the continuous updating and progress of drug resistance testing methods in the medical field. At the same time, thanks to the application of deep learning technology in drug research and development, people have also made many beneficial explorations and attempts [13-15]. The study of gene expression and protein structure, compound screening, and the design and analysis of clinical trials for drug design are all influenced by artificial technology. In addition, the application of various digital devices in clinical trials and daily patient monitoring will also benefit from the help of artificial intelligence technology. Driven by machine learning and deep learning technologies, significant progress has been made in the analysis of antimicrobial resistance testing in the medical field. By using CNN technology in deep learning, testers can obtain more detailed data on antimicrobial resistance testing and analysis, and conduct more effective research and analysis on drug resistance, Furthermore, more accurate drug resistance diagnosis and prediction can be made for patients [16]. The application of deep learning algorithms in the testing of antimicrobial resistance can help evaluate drug resistance in a shorter time with fewer cases and reduce the cost of clinical trials. As shown in Fig. 3, a schematic diagram of the application of the CNN algorithm model in drug resistance testing and analysis is provided.

Based on deep learning algorithms, comprehensive analysis of a large amount of antimicrobial resistance testing data has become a trend in the medical field. In traditional medical practices, doctors also use antibiotics based on their

own experience and habits, lacking a more systematic and comprehensive consideration of the indications and contraindications of antibiotics, as well as the personal characteristics of patients [17]. A deep learning based identification model for antibacterial drug applications. Firstly, the coding distribution representation of the antibacterial drug is obtained. Then, a CNN model is trained for feature extraction and self-learning. Finally, a reasonable rule and feature library for single disease and complications is generated. Therefore, using the CNN model in deep learning algorithms can more efficiently detect and analyze antimicrobial resistance [18].



*Convolutional Neural Network*

*Target drug information* — *Input layer* — *Hidden layer* — *Output layer* — *Analysis of drug resistance testing*
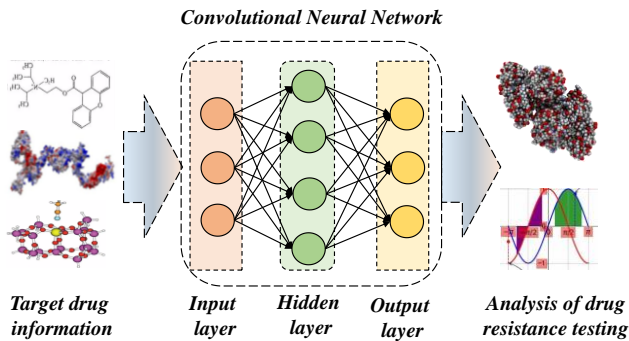
Fig. 3.  Application of CNN algorithm in drug resistance testing and analysis.

## III. Construction of a Drug Testing Model Based on CNN Algorithm

### A. CNN Algorithm Theory

CNNs are mainly used in fields such as image processing and recognition. They are a multi-layer perception mechanism mainly used to process two-dimensional images. As shown in Fig. 4, a schematic diagram of the CNN module in deep learning algorithms is provided. The basic structure of CNN consists of an input layer, a convolutional layer, a pooling layer, a fully connected layer, and an output layer. The pooling layer merges adjacent multiple nodes into a similar feature to reduce the amount of training data, extract hidden features from the project, conduct multi-layer training, and perform dimensionality reduction processing. Finally, the CNN is trained as a whole [19-20].



*Input layer* — *Output layer*

*Convolution* — *Pooling* — *Convolution* — *Pooling* — *Convolution* — *Fully connected*
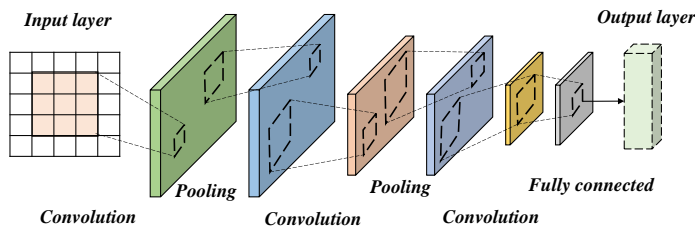
Fig. 4.  Schematic diagram of CNN model.

In the CNN model algorithm, $L$ represents the number of layers of the neural network, $i$ represents the label of a certain layer, then $w_{h,w}^{i}$ represents the connection weight from the wth neuron in layer $i$-1 to the $h$-th neuron in layer $i$, $b_h^i$ represents the bias of the $h$-th neuron in layer $i$, and $Z_h^i$

represents the weighted input of the $h$-th neuron in layer $l$. The weighted input of the $h$-th neuron in the l-th layer can be represented by Formula (1):

$$Z_h^i = \sum_h w_{h,w}^i a_w^{i-1} + b_h^i \qquad (1)$$

For convolutional layers, their main function is to extract features, perform convolution calculations on the vectorized text vector and the convolution sum, and perform operations on extracting word information before and after. The obtained convolution results are processed through activation function operations, and the convolution function results are used as the output results of this layer. The convolutional kernel is represented by $w$, where $w \in R^{hk}$. Where $h$ represents the height of the convolutional kernel window, and $k$ represents the dimensional size of the word vector. $W_{ih}$ represents a sequence of words with a length of h ($W_i$, $W_{i+1}$, …, $W_{i+h}$), Wi represents a word, and the value of each eigenvalue can be calculated using Formula (2):

$$y_i = f(\sum_{h=1}^{n} \sum_{w=1}^{n} \sum_{d=1}^{m} x_{h,w,d} \times w_{h,w,d}^i + b^i) \qquad (2)$$

Among them, $n$ represents the height and width of the convolutional kernel, $m$ represents the depth of the convolutional kernel, $x_{h,w,d}$ represents the value at the region connected to the convolutional kernel ($h$, $w$, $d$), $w_{h,w,d}^i$ represents the weight parameter at the convolutional kernel ($h$, $w$, $d$), $b^i$ represents the bias of the convolutional kernel, and $f(\cdot)$ represents the activation function. In addition, the input layer $x$ is convolved to obtain the feature vector $y$, which can be represented by Formula (3):

$$y = (y_1, y_2, y_3, ..., y_{i-h+1}) \qquad (3)$$

In addition, the pooling layer can reduce the dimensionality of the extracted feature information, reducing the size of the feature map, simplifying the computational complexity of the network, and avoiding overfitting to a certain extent. On the one hand, feature compression is performed to extract the main features. This layer is mainly used to reduce the dimensionality of the feature map obtained by convolution, and the maximum pooling method shown in Formula (4) is often used to extract local optimal values:

$$Y = max(y_i) \qquad (4)$$

The fully connected layer in a CNN is usually located after several convolutional and pooling layers, and is also the last few layers of the CNN. Its essence is a multi-layer perceptron model, where each neuron in the fully connected layer is connected to all neurons in the previous layer. The most direct function of the fully connected layer is to compress the two-dimensional feature map into a one-dimensional feature vector, in order to connect with the final output layer of the network to output the final classification results [21]. At the same time, it can also to some extent integrate local information with class differentiation in convolutional and pooling layers. The role of the previous convolutional and

pooling layers is to map a shallow feature into a deep feature space, while the fully connected layer maps these deep feature representations into the classification space of the class. Therefore, the fully connected layer also has a certain classification effect.

The use of nonlinear factors can better solve complex problems, and activation functions can help introduce nonlinear factors, adding some nonlinear factors to neural networks, and enabling neural networks to better solve more complex problems. Common saturated linear functions include *Sigmoid*, *Tanh* function, and *Tanh* activation function, which converge faster than *Sigmoid*, but there is still a phenomenon of gradient vanishing during training [22-23]. As shown in Formulas (5) and (6), the activation function expression is given:

$$Sigmoidf(x) = \frac{1}{1+e^{-x}} \qquad (5)$$

$$Tanhf(x) = \frac{e^x - e^{-x}}{e^x + e^{-x}} \qquad (6)$$

In this article, the specific method is first based on deep learning methods. The input part involves the name, function, dosage, indication, contraindications, etc. of antibacterial drugs. The word vector tool is used to train the word vector, and then the transformed sentence is input into a CNN for convolution and pooling. Then, the fully connected deep learning features are obtained.

### B. Construction of Drug Testing Model Based on CNN Algorithm

*1) Text classification*: In the medical field, text classification of data is required when using CNN algorithm for antibiotic resistance testing and analysis. Text vector is a higher-level expression of text, which can be used as a partial feature vector for antibacterial drug text data classification. After training and learning through standard neural networks, vector V is obtained as another basis for antibacterial drug text data classification [24]. The weights of feature vectors in classification are α and (1-α). The probability calculation formula for text belonging to a certain type of effect is shown in equation (7):

$$P = softmax\left[\alpha \times W_c C + (1-\alpha) \times W_c H + b_c\right] \qquad (7)$$

Using the negative logarithmic likelihood of the correct label as the training loss, the calculation formula is shown in formula (8):

$$L = -\sum_d log_a x d_j \qquad (8)$$

Where $j$ is the label of text $d$, $R = 1 - \frac{C}{A+C}$ represents the probability that text $d$ belongs to effect $j$.

*2) Modeling of drug sensitivity testing data:* The dual channel CNN model proposed in this article integrates attention mechanism. After preprocessing the original test data, it is vectorized and modeled. As input data, it is sent to the CNN of two independent and different depth channels. After each channel undergoes several convolutional and pooling operations, attention mechanism is introduced. By fitting multiple sets of weight vectors to characterize the importance of each feature component, the feature data of the two channels is fused, and finally, the softmax function is used to achieve classification output. The data source studied in this article is bacterial drug sensitivity testing data. Each test sample includes the patient's age, gender, department, submission date, sample type, bacterial species, testing chemical reagents, testing report date, and other submission data, as well as the patient's minimum inhibitory concentration (MIC) testing results for each antibacterial drug. With the development of physical, chemical, and molecular biology technologies, various new bacterial resistance testing technologies have emerged. As shown in Table I, common chemical methods and their characteristics for detecting antimicrobial resistance are presented.

TABLE I. CHEMICAL METHODS AND CHARACTERISTICS OF ANTIMICROBIAL RESISTANCE TESTING [25-26]

| Method | Characteristics | Application Scenario |
|---|---|---|
| Nucleic acid hybridization technology | Short testing time, time-saving and fast, strong specificity, and high sensitivity | Rapid diagnosis of pathogens in clinical settings |
| PCR | Short testing time, time-saving and fast | Rapid diagnosis of pathogens in clinical settings |
| Disk diffusion | Simple, repeatable, without the need for expensive device support | Qualitative testing of bacterial sensitivity to antibiotics |
| Testing method based on time-of-flight mass spectrometry technology | Microbial cultivation takes a long time and requires exploration of antibiotic usage conditions | Rapid testing of drug resistance |

Select multiple attributes from the submitted data that may affect the tolerance value of antibacterial drugs as input features, and use the testing result MIC as a classification label. Considering that different bacterial strains have different sensitivities to the same antibacterial drug, and the sensitivity values of the same bacterial strain to the same antibacterial drug vary among different specimens [27]. Therefore, it is necessary to establish a classification model for each antibacterial drug, and output its MIC classification value for the current antibacterial drug based on the input multi feature test data. The vectorized representation of sample data containing multiple features is an important prerequisite for feature extraction and fusion using CNNs. This article draws inspiration from the approach of constructing a word vector model in text problems, where each attribute feature value corresponds to a word and is represented by a vector. The dimension of the feature vector is the number of all feature values. As the feature vector dimension of the drug sensitivity data selected in this article is 48, there is no problem of dimensional disaster, and the correlation between various features is relatively weak. Therefore, the traditional *One-hot* method is used to construct the feature vector model. A sample

data containing multiple features corresponds to a sentence in the text problem, which is modeled as a two-dimensional matrix, and each row of the matrix is a feature vector. As shown in Fig. 5, a dual channel convolutional neural network model structure diagram integrating attention mechanism is presented.
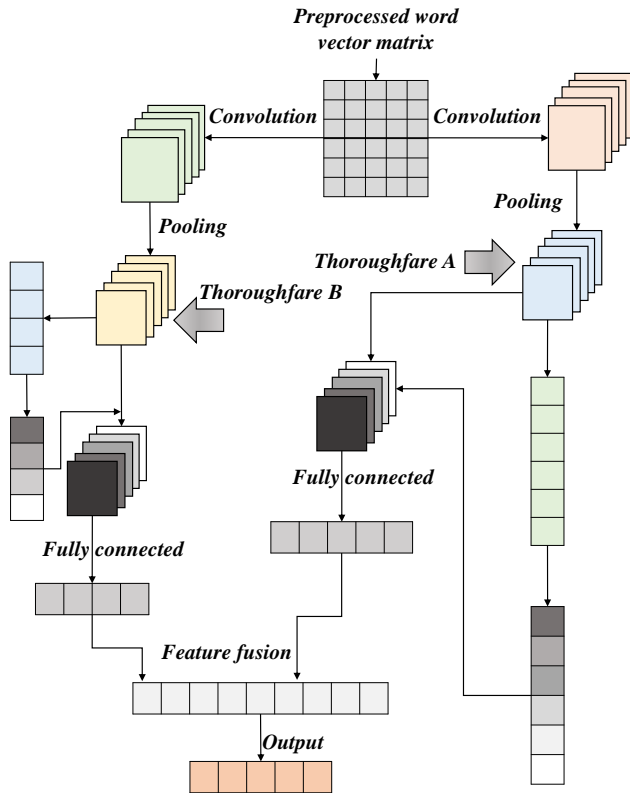


Fig. 5. A dual channel CNN model integrating attention mechanism.

The features extracted by CNNs are often related to the depth of the network. The deeper the network level, the easier it is to extract abstract features that represent the whole. The shallower the network level, the easier it is to extract detailed features that represent local regions. In view of this, this article designs two types of dual channel CNNs with depths of six and four layers, respectively, to extract features at different levels of abstraction in deep and shallow layers. In addition, considering that the feature matrix size of the testing sample is not large, pooling dimensionality reduction is weakened. The upper channel network consists of five convolutional layers with different kernel sizes and numbers, three maximum pooling layers with the same step size, and 1 fully connected layer, the down channel network consists of three convolutional layers with different kernel sizes and numbers, one maximum pooling layer, and one fully connected layer.

*3) Attention mechanism and model training:* The implementation of the Attention Mechanism is achieved by preserving the intermediate output results of the CNN encoder on the input sequence, and then training a model to selectively learn these inputs and associate the output sequence with them when the model outputs [28-29]. Although the model may increase computational complexity after using this

mechanism, its performance level can be improved. In addition, using this mechanism helps to analyze the impact of relevant information on the final generated sequence.

The attention mechanism assigns appropriate weights to each feature component, selects important features, and focuses on this information. It is divided into three parts, namely Squeeze, Excitation, and Attention. Assuming that the feature information after convolution and pooling is a two-dimensional matrix containing $n$ feature vectors, denoted as $U_{m \times n}$, after squeezing, the vector $Z$ is obtained. The calculation of the squeezing function ($F_{sq}$) is shown in Formula (9):

$$Z = \sum_{i=1}^{m} U_i \bigg/ m \tag{9}$$

The vector $Z$ is stimulated by Formula (10) to obtain the attention weight vector $a$. Multiply the weight vector $a$ with the feature matrix $U$ to generate a feature output $U'$ with attention mechanism, and $U'=aU$.

$$a = softmax\left[ w_s \times tanh(w_z \times z) \right] \tag{10}$$

where, $m$ is the dimension of the feature vector, $U_i$ is the *i-th* feature vector, *softmax* (·) and *tanh*(·) are activation functions, and $w_s$ and $w_z$ are learnable weight matrices.

In addition, during the model training process in the CNN algorithm, the *softmax* function is used to classify the feature vectors after dual channel fusion, and the predicted probability value $P(k|x)$ of the output result category is shown in Formula (11):

$$P(k|x) = e^{x|k|} \bigg/ \sum_{i=1}^{n} e^{x|i|} \tag{11}$$

The cross-entropy loss function is used to measure the difference between the predicted probability and the real label, and the calculation is shown in Formula (12). This is used for backpropagation training of the model, with the goal of minimizing the loss of the function [30]:

$$L = \sum_{i=1}^{n} q(k|x) log\left[ P(k|x) \right] \tag{12}$$

where, $q(k|x)$ represents the actual encoding vector of the corresponding category $k$ of the current sample, which is the real label.

## IV. ANALYSIS OF DRUG RESISTANCE TESTING AND MODEL APPLICATION

### A. Drug Resistance Testing

*1) Source of strains and testing instruments:* When using a deep learning CNN algorithm to detect antimicrobial resistance, the relevant data comes from bacterial drug sensitivity testing data in a tertiary hospital's intensive care

unit. 120 strains of Acinetobacter baumannii were isolated from clinical specimens, and duplicate strains from the same patient and site were discarded. The standard strains are Escherichia coli ATCC25922 and Pseudomonas aeruginosa ATCC27853, using drugs such as Ampicillin/Sulbactam (AMP/SCF), Fefepime (FEP), Cefoperazone/Sulbactam (CSL/SCF), Cefotaxime (CTX), Ceftazidime (CAZ), Ceftriaxone (CRO), Ciprofloxacin (CIP), Gentamicin (GEN), Imipenem (IMP), Meropenem (MEM), Piperacillin/Tazobactam (TZP). Piperacillin (PIP), Levofloxacin (LVX), Amikacin (AMK), Compound Sulfamethoxazole (SXT). In addition, the culture medium is Mueller Hunton (M-H) agar and broth. As shown in Table II, the relevant equipment for drug resistance testing is provided.

TABLE II.    DRUG RESISTANCE TESTING EQUIPMENT AND INSTRUMENTS

| Types | Device |
|---|---|
| Main instruments | Ultra low temperature water tank |
| | A400 multi-point vaccination device |
| | Electro-heating standing-temperature cultivator |
| | VITEK Microbial Fully Automatic Identification Instrument |
| | Paper dispenser |
| | JY2002 Electronic Balance |
| | ZHP-2102 Intelligent Constant Temperature Shaker Incubator |
| Other auxiliary instruments | Pipette, glass test tube, PCR tube, EP tube, bacterial culture dish, etc |

*2) Drug resistance testing methods:* The sensitivity of antibacterial drugs was determined using K-B agar diffusion method and M-H agar dilution method. The screening criteria for multiple drug resistance were: Acinetobacter Baumanii against cephalosporins, aminoglycosides, carbapenems, and enzyme inhibitors β Individuals with resistance to three or more antibiotics, including lactams and fluoroquinolones, are identified as multidrug-resistant Acinetobacter baumannii.

For the preparation of flat plates, it is necessary to mark the different concentrations on the plates, dilute the antibiotic stock solution, and then pour the antibiotics into the plates using a double dilution method. Wait for M-H agar to cool to about 50℃, and pour a certain amount of antibacterial drugs into the plate with the calculated final concentration. Inoculate the quality control strain and the test strain onto an M-H agar plate, incubate overnight at 37℃, and then select 4~5 colonies to be cultured overnight in 1ml of M-H broth. Dilute 10 times, which is equivalent to 0.5 Mach's turbidity. Dip the bacterial solution with a multi-point inoculum and inoculate it onto an antibacterial drug plate. The amount of inoculation per point is approximately $10^4$~$10^5$CFU. Place the inoculated antibacterial drug plate in an incubator at 35℃ for 20~24 hours and observe the results. Each operation includes quality control strains.

In addition, for the drug sensitivity testing process, the antibacterial *K-B* method is used to determine the size of the antibacterial zone. The fresh pure bacterial solution with a concentration of 0.5 microns is uniformly coated with sterile cotton swabs on a 4mm thick and 90mm diameter M-H agar drug sensitive plate. Each plate is coated with six pieces of drug sensitive paper, and incubated at 35℃ for 16~18 hours to measure the size of the antibacterial zone on the plate and interpret the results. The results were determined to be sensitive, medium sensitive, or resistant according to the relevant regulations regarding the size of the antibacterial zone.

*B. Application and Analysis of Testing Models*

Based on the above statistics of antimicrobial resistance testing results, a total of 12765 related data were completed. The actual production data is quite complex and must be preprocessed before being used in experiments. The data preprocessing work in this article includes data filtering and screening, outlier testing, and standardization. Firstly, data filtering involves screening raw data, removing irrelevant indicators, and selecting six attribute features that may affect antimicrobial resistance values as inputs. The corresponding feature inputs are patient gender, patient age, source department, specimen type, bacterial species, and related chemical detection methods. Secondly, outlier testing is mainly based on expert testing experience to identify unreasonable testing results in the original data. At the same time, testing samples with more missing values and fewer records are also included in the outlier data. The final dataset used for the experiment consists of 3562 pieces. Then there is the standardization of data processing, mainly for the convenience of later data processing, quantifying the five features using numerical values to achieve unified quantization methods.

*1) Evaluating indicators:* In the process of detecting antimicrobial resistance, this article uses the F metric value as the evaluation criterion for the classification results. The process of classifying the test text d in this method is as follows: first, calculate the text similarity between d and each text in the training sample set. The similarity is generally measured using Euclidean distance, and based on the text similarity, find the most similar K closest training texts. The K sample categories are used as candidate categories for d, Then, based on the similarity between the text to be classified d and these K neighbors, the weight of the K nearest neighbor text category is used. The sum of the class weights of the neighboring texts in each category is used as the similarity between the category and the test text. Then, the text to be classified d is divided into the category with the highest weight. The calculation process of text similarity between the text d and di to be classified is given by Formula (13):

$$Sim(d_i,d) = \frac{1}{d - d_i} = \frac{1}{\sqrt{\sum_{j=1}^{n}(x_{i,j} - x_j)^2}} \qquad (13)$$

For the weight of the sample *d* to be classified and the $c_j$ of each class, Formula (14) can be used to calculate:

$$p(d,c_j)=\sum_{i=1}^{n} sim(d_i,d)\,y(d_i,c_j) \qquad (14)$$

where, $y(d_i,c_j)$ is a class attribute function, and when $d_i \in c_j$, there exists $y(d_i, c_j)=1$. When $d_i \notin c_j$, $y(d_i, c_j)=0$.

In addition, this method takes into account both precision (*P*) and recall (*R*) indicators, with *P*, *R*, and *F* calculated by Formula (15):

$$\begin{cases} P = \dfrac{TP}{TP+FP} \\ R = \dfrac{TP}{TP+FN} \\ F = \dfrac{2 \times P \times R}{P+R} \end{cases} \qquad (15)$$

where, *TP* represents the number of samples divided into positive classes, *FP* represents the number of samples divided into positive classes for negative classes, *FN* represents the number of samples divided into negative classes for positive classes, *TP+FP* represents the actual number of samples classified, and *TP+FN* represents the expected number of samples.

To further analyze the accuracy of antimicrobial resistance testing, Formula (16) can be used to determine the accuracy of the test results:

$$Accuracy=\frac{TP+TN}{TP+FP+TN+FN} \qquad (16)$$

*2) Experimental environment and parameters:* To ensure the objectivity and effectiveness of antimicrobial resistance testing results, a ten fold cross validation method was adopted in the experiment. The dataset was divided into te parts, with 1 part being the test set and the remaining nine parts being the training set. The 10 samples were randomly rotated for 10 experiments, and the average value was taken as the final result of the model. After multiple experiments, a set of optimal model parameters was determined, and the relevant values are shown in Table III.

TABLE III.     SETTING OF MAIN PARAMETERS OF THE MODEL

| Parameters | Parameter Value |
|---|---|
| Number of convolutional kernels in the upper channel (channel A) | 64,128,128,128, 128 |
| Number of convolutional kernels in the lower channel (channel B) | 64,128,128 |
| Upper channel convolution kernel size (channel A) | 2,3,3,3,2 |
| Lower channel convolution kernel size (channel B) | 2,3,2 |
| Output layer ratio | 0.5 |
| Learning rate | 0.001 |
| Maximum number of iterations | 500 |

To better evaluate the classification performance of the dual channel CNN model (CNN-ATT-TChan) proposed in this article, which integrates attention mechanisms, in antimicrobial resistance testing data, comparative experiments were designed between different models. As shown in Table IV, the types and basic information of the models used for comparison are provided.

TABLE IV.     COMPARISON OF DIFFERENT TYPES OF MODELS

| Models | Description |
|---|---|
| CNN-2D | The convolution kernel of this model is two-dimensional, including multi-layer convolution and pooling operations. |
| CNN-2D-ATT | This model adds an attention mechanism based on feature components on the basis of CNN-2D. |
| CNN-2D-TChan | This model is based on CNN-2D and designed with two upper and lower channels, which perform multiple convolution and pooling operations for feature fusion and achieve classification output. |
| CNN-1D-MChan | This model adopts multiple one-dimensional convolutional kernels with different widths but the same length, each with a length equal to the feature vector dimension of drug sensitivity data. |
| CNN-1D-Mchan-NP | This model is based on CNN-1D-MChan and removes pooling operations. After each channel undergoes one-dimensional convolution, it directly performs vector fusion and enters the fully connected layer. |
| ResNet-18 | The basic architecture of this model is *ResNet,* with a depth of 18 layers (referring to the weight layer of the network), excluding the batch normalization layer and pooling layer |
| RF | The random forest algorithm model is a mainstream ensemble learning method used for classification and regression. |

*3) Analysis of model testing results:* Based on the sorting and analysis of the above basic models, in order to verify the impact of adding attention mechanisms in one-dimensional and two-dimensional convolution models on model performance, as shown in Fig. 6, the impact of attention mechanisms on model training duration in one-dimensional and two-dimensional convolution cases is presented. As shown in the figure, for a two-dimensional convolutional model, with the assistance of spatial domain attention mechanism and mixed attention mechanism (spatial+channel), the main role of attention mechanism in one-dimensional convolution and two-dimensional convolution is to significantly increase the training time of the model. For the two-dimensional convolutional model, with the introduction of attention mechanism, when Epochs is 500, the two are 604s and 501s respectively, with a difference of 103s, which is about 20.5% higher overall. In the one-dimensional convolutional model, after introducing attention mechanism, the training duration of the two is 298s and 258s respectively (when Epochs is 500), with a difference of 15.5% between the two. Therefore, it can be seen that when attention mechanism is introduced, the training duration of both will increase to varying degrees. After adding attention mechanism, the training duration has been improved to a certain extent. The training duration of one-dimensional convolutional network

(CNN-1D-ATT) with added attention mechanism is relatively small compared to one-dimensional convolutional network (CNN-1D) without added attention mechanism. The two-dimensional convolutional network (CNN-2D-ATT) with added attention mechanism has significantly improved and improved training time compared to the two-dimensional convolutional network without added attention mechanism (CNN-2D), which also lays the foundation for the accuracy of antimicrobial resistance analysis.



a) Comparison between CNN-2D-ATT and CNN-2D models



b) Comparison between CNN-1D-ATT and CNN-1D models
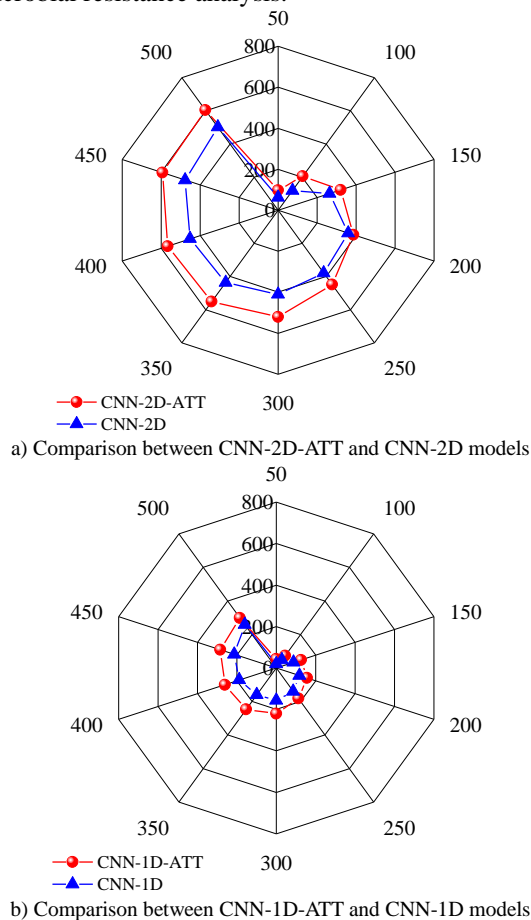
Fig. 6.    Impact of introducing attention mechanism into 1D/2D models on training duration.

Based on the analysis of the training duration of relevant models, in order to further analyze the impact of attention mechanism introduction on the accuracy of different models, as shown in Fig. 7, the trend of F values of one-dimensional convolutional models and two-dimensional convolutional models under different Epochs is presented. As shown in the figure, for the two-dimensional CNN model, with the introduction of attention mechanism, the classification accuracy of CNN-2D-ATT is significantly higher than that of CNN-2D. For example, when Epochs is 500, the F values of the two are 76.1% and 66.4%, respectively, with an overall

difference of 9.7%. At the same time, comparing one-dimensional CNN models that also introduce attention training mechanism with two-dimensional CNN models, it can be found that when Epochs is 500, the former has an F-value of 57.2%, while the latter has an F-value of 76.1%, an improvement of about 18.9%, and the improvement effect is significant. The main reason for the improvement and enhancement of this effect is, on the one hand, due to the small number of layers in the one-dimensional convolutional network model, resulting in a decrease in the overall complexity of the network model. On the other hand, the reduction in the size of the convolutional kernel and output feature during the one-dimensional convolutional process leads to a decrease in the time complexity of individual convolutional layers.
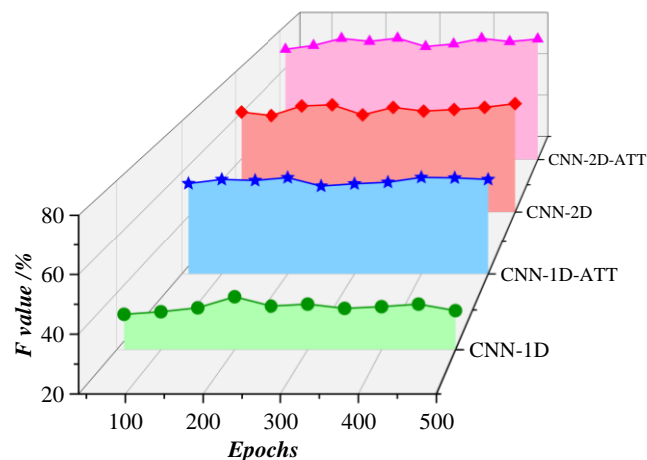


Fig. 7.    The influence of attention mechanism on F-value in 1D/2D models.

In addition, in order to compare the overall performance of the model constructed in this article (CNN-ATT-TChan) with other models, based on the analysis of the overall performance of different models, as shown in Fig. 8 and Fig. 9, the F-values of different models and the changes in training time of different models were presented. From Fig. 8, it can be seen that in the comparison of the F values of the above models, the maximum value is the CNN-ATT-TChan model, which is about 72.4%, indicating that the model has better overall performance and can demonstrate better classification accuracy. The model with the lowest F-value is the CNN-1D Mchan model, which is approximately 50.6%. In addition, in Fig. 7, the comparison of the training time of different models with Epoch of 50 is shown. The average time of the above models is about 166 seconds, and the ResNet-18 model with the longest required time is about 653 seconds. The training duration of the CNN-ATT-TChan model is approximately 103 seconds, which is a decrease of 63 seconds compared to the average. Therefore, the CNN-ATT-TChan model constructed in this paper exhibits good classification performance when the experimental data for antimicrobial resistance testing is large and the amount of feature engineering is increased.
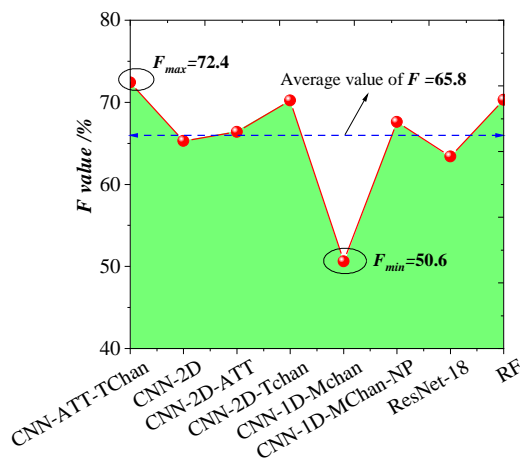
Fig. 8.  Comparison of F-values in different calculation models.
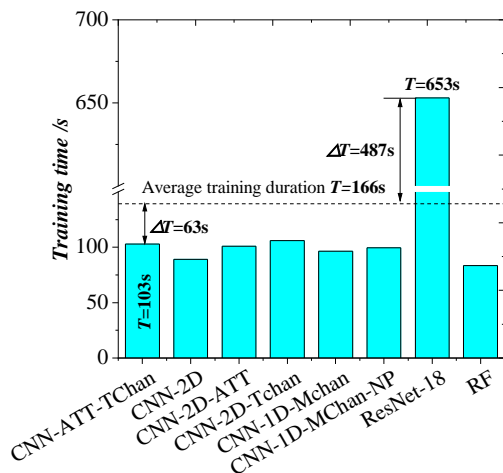


Fig. 9.  Comparison of training time for different models.

As shown in Fig. 10, a comparison of the ROC curves between this model and other model is presented. From the figure, it can be seen that the AUC corresponding to the ROC curve in this paper is 0.86, while the AUC of the VGGC16+LSTM model in study [31] is about 0.71. Therefore, the model in this article has better detection performance.
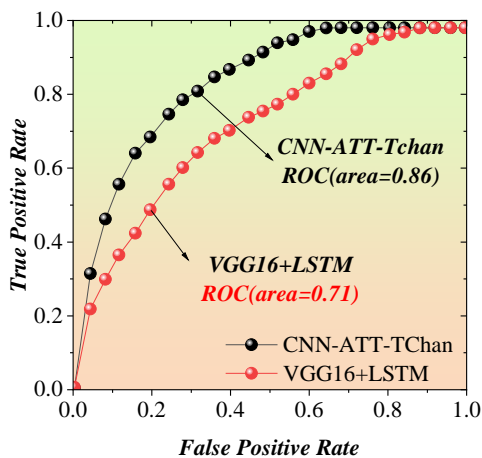


Fig. 10.  Average ROC curves of different models.

Through the comparison of the above models and related indicators, it can be found that the CNN ATT Tchan model constructed in this article can effectively improve the problems of low detection accuracy and relatively long detection time in traditional models in drug detection. While solving the problem of low detection accuracy, it achieves the goal of shortening the detection cycle of antibiotic resistance. In this article, improvements have been made in model detection efficiency and detection cycle performance, but further research on drug resistance detection is still a worthwhile direction. For example, deeper research can be conducted by combining a large amount of clinical data, providing more support for drug resistance testing work.

## V.  CONCLUSIONS

The continuous development and application of CNN algorithm in deep learning technology have promoted the continuous progress of antimicrobial resistance testing technology in the medical field. This article constructs a CNN-ATT-TChan model based on the application of CNN algorithm in drug resistance testing, and compares and analyzes the performance of this model in antimicrobial drug resistance testing. The changes in the training time and classification accuracy of the model are presented. The main conclusions are as follows:

By combining the CNN algorithm and attention mechanism, the constructed CNN-ATT-TChan antibacterial drug resistance testing and analysis model can achieve better overall testing performance compared to other models. It can effectively improve important parameters such as training time and classification accuracy in the antibacterial drug resistance testing process in the medical field, and achieve improved testing performance.

By integrating attention mechanism into one-dimensional CNN and two-dimensional CNN models, for two-dimensional CNN models, with the introduction of attention mechanism, when Epochs is 500, the training duration is increased by about 20.5%. In the one-dimensional CNN model, the introduction of attention mechanism resulted in a 15.5% increase in training time.

The constructed CNN-ATT-TChan antibacterial drug resistance testing model exhibits better overall classification accuracy and small sample classification, with certain feasibility and effectiveness. Compared to other models, the classification accuracy can be improved by up to 21.8%.

## REFERENCES

[1]  M. M. Bendary, M. I. Abd El-Hamid, A. I. Abousaty, et al., Therapeutic Switching of Rafoxanide: a New Approach To Fighting Drug-Resistant Bacteria and Fungi. Microbiology spectrum, 2023, 12(2): 124-139. https://doi.org/10.1128/spectrum.02679-22

[2]  D. Zhang, F. Yin, Q. Qin, & L. Qiao, Molecular responses during bacterial filamentation reveal inhibition methods of drug-resistant

bacteria. Proceedings of the National Academy of Sciences of the United States of America, 2023, 120(27): 12-27. https://doi.org/10.1073/pnas.2301170120

[3] M. Harris, Machine Learning and Artificial Intelligence for Pathogen Identification and Antibiotic Resistance Detection: Advancing Diagnostics for Urinary Tract Infections. BioMed, 2023, 3(2): 246-255. https://doi.org/10.3390/biomed3020022

[4] S. N. Helen, S. D. İlayda, A. E. Daniel, Direct microfluidic antibiotic resistance testing in urine with smartphone capture: significant variation in sample matrix interference between individual human urine samples. RSC advances, 2021, 11(60): 258-263. https://doi.org/10.1039/D1RA06867A

[5] A. Fergus, N. Tim, Antimicrobial use: importance of bacterial culture and susceptibility testing. In Practice, 2021, 43(9): 500-510. https://doi.org/10.1039/W1RA45168B

[6] T. Rui, L. Rui, T. Shiwei, et al., Machine learning in predicting antimicrobial resistance: a systematic review and meta-analysis. International journal of antimicrobial agents, 2022, 60(5-6): 625-645. https://doi.org/10.3290/antibiotics110568924

[7] J. K. In, M. Finlay, K. K. T., et al., Machine Learning for Antimicrobial Resistance Prediction: Current Practice, Limitations, and Clinical Perspective. Clinical microbiology reviews, 2022, 22(6). https://doi.org/12.1239/s41467-022-2593623.

[8] Y. Ren, T. Chakraborty, S. Doijad, et al., Prediction of antimicrobial resistance based on whole-genome sequencing and machine learning. Bioinformatics (Oxford, England), 2021, 38(2): 325-334. https://doi.org/10.1093/bioinformatics/btab681

[9] L. Murray, A. Boxall, J. Snape, et al., The selection and co-selection of antimicrobial resistance by non-antibiotic drugs and plant protection products. Access Microbiology, 2020, 2(7A). https://doi.org/10.2190/s41467-022-259

[10] M. M. Magdalena, C. Carmen, R. Elena, et al., Urinary Tract Infections in Patients with Type 1 and Type 2 Diabetes: Etiology, Resistance to Antibacterial Chemicals and Virulence Features. Revista de Chimie, 2017, 68(3): 566-569. https://doi.org/10.19982/j.issn.1000-6621.20170161.

[11] A. Tabish, A. Sarfaraz, A. Muhammad, Artificial Intelligence for Antimicrobial Resistance Prediction: Challenges and Opportunities towards Practical Implementation. Antibiotics, 2023, 12(3). https://doi:10.13881/j.cnki.hljxmsy.2023.06.0095.

[12] A. G. Green, C. H. Yoon, M. L. Chen, et al., A convolutional neural network highlights mutations relevant to antimicrobial resistance in Mycobacterium tuberculosis. Nature communications, 2022, 13(1): 817-829. https://doi.org/10.1038/s41467-022-31236-0

[13] Özçelik Rıza, van Tilborg Derek, JiménezLuna José. Structure-based Drug discovery with Deep Learning. Chembiochem: a European journal of chemical biology, 2023, 12(8): 213-236. https://doi.org/10.19937/j.issn.1671-4199.2023.03.029.

[14] M. Jamshidi, O. Moztarzadeh, A. Jamshidi, et al., Future of Drug Discovery: The Synergy of Edge Computing, Internet of Medical Things, and Deep Learning. Future Internet, 2023, 15(4). https://doi.org/10.16431/j.cnki.1671-7236.2023.02.032.

[15] A. A. Keshavarzi, S. Milad, K. Heather, et al. Functional microRNA-Targeting Drug Discovery by Graph-Based Deep Learning. bioRxiv: the preprint server for biology, 2023. https://doi.org/10.16718/j.1009-7708.2023.05.020.

[16] K. D. Stergiou, G. M. Minopoulos, V. A. Memos, et al., A Machine Learning-Based Model for Epidemic Forecasting and Faster Drug Discovery. Applied Sciences, 2022, 12(21): 328-352. https://doi.org/10.3390/app122110766

[17] C. Hitesh, A. B. Amin, R. G. K., et al., Application of Artificial intelligence in Drug Discovery. Current pharmaceutical design, 2022. https://doi.org/10.16437/j.cnki.1007-5038.2022.03.016.

[18] K. Yanagisawa, M. Toratani, A. Asai, et al., Convolutional Neural Network Can Recognize Drug Resistance of Single Cancer Cells. International Journal of Molecular Sciences, 2020, 21(9): 316-328. https://doi.org/10.16718/j.1219-7908.2020.05.035.

[19] Z. N. Khan, J. Ahmad, Attention induced multi-head convolutional neural network for human activity recognition. Applied Soft Computing Journal, 2021, 11(6): 45-57. https://doi.org/10.1016/j.asoc.2021.107671

[20] R. Shubhankar, K. P. S. R, K. Vineet, A novel complex-valued convolutional neural network for medical image denoising. Biomedical Signal Processing and Control, 2021, 69. https://doi.org/10.25638/j.1009-8978.2021.05.032.

[21] T. Chao, L. Shuhua, D. Feng, et al., Image Reconstruction Based on Convolutional Neural Network for Electrical Resistance Tomography. IEEE Sensors Journal, 2019, 19(1):196-204. https://doi.org/10.1080/15257770.2019.2153251

[22] Y. Ülger, A. Delik, Artificial intelligence model with deep learning in nonalcoholic fatty liver disease diagnosis: genetic based artificial neural networks. Nucleosides, Nucleotides & Nucleic Acids, 2023, 42(5): 398-406. https://doi.org/10.1080/15257770.2022.2152046

[23] A. Tabish, A. Sarfaraz, A. Muhammad, Artificial Intelligence for Antimicrobial Resistance Prediction: Challenges and Opportunities towards Practical Implementation. Antibiotics, 2023, 12(3): 523-538. https://doi.org/10.1023/15145980.2023.269875

[24] S. Aikaterini, K. Christina, F. Georgios, et al. Using Machine Learning to Predict Antimicrobial Resistance—A Literature Review. Antibiotics, 2023, 12(3): 452-476. https://doi.org/10.16003/j.cnki.issn1672-5190.2023.03.006.

[25] A. A. Rabaan, S. Alhumaid, A. A. Mutair, et al., Application of Artificial Intelligence in Combating High Antimicrobial Resistance Rates. Antibiotics, 2022, 11(6): 784-798. https://doi.org/10.3390/antibiotics11060784

[26] L. Yuying, F. Tao, W. Yan, The role of bacterial signaling networks in antibiotics response and resistance regulation. Marine Life Science & Technology, 2022, 4(2):163-178. https://doi.org/10.16458/j.cnki.1007-0893.2022.06.002.

[27] B. Beatriz, A. C. Beatriz, M.S. P S, et al., Network biology and artificial intelligence drive the understanding of the multidrug resistance phenotype in cancer. Drug Resistance Updates, 2022, 60. https://doi.org/10.16437/j.cnki.1007-5038.2022.07.010.

[28] T. Hao, X. Chao, H. Xu, Electrical resistance tomography image reconstruction based on one-dimensional multi-branch convolutional neural network combined with attention mechanism. Flow Measurement and Instrumentation, 2022, 84. https://doi.org/10.19386/j.cnki.jxnyxb.2022.10.024.

[29] A. K. Bagherian, S. Sadaf, N. Mohammadjavad, et al., Point-of-Interest Preference Model Using an Attention Mechanism in a Convolutional Neural Network. Bioengineering (Basel, Switzerland), 2023, 10(4). https://doi.org/10.16485/j.issn.2095-7858.2023.01.007.

[30] W. Ziye, L. Shuo, Y. Ronghui, et al., ARG-SHINE: improve antibiotic resistance class prediction by integrating sequence homology, functional information and deep convolutional neural network. NAR genomics and bioinformatics, 2021, 3(3): 66-79. https://doi.org/10.16863/j.cnki.1003-6377.2021.04.011.

[31] Wei Tao. Research on the prediction method of drug resistance of nonsmall cell lung cancer based on deep learning. Guangxi University, Nanning, China. 2021. https://doi.org/10.27034/d.cnki.ggxiu.2020.002152.

# Multi-Scale Deep Learning-based Recurrent Neural Network for Improved Medical Image Restoration and Enhancement

Dr. A.B. Pawar[1], Dr C Priya[2], Dr. V.V. Jaya Rama Krishnaiah[3], Dr. V. Antony Asir Daniel[4],
Prof. Ts. Dr. Yousef A.Baker El-Ebiary[5], Ahmed I. Taloba[6]

Professor, Dept of Computer Engineering, Sanjivani College of Engineering
Kopargaon Savitribai Phule Pune University, Pune[1]
Associate Professor of EEE, Sri Sairam Engineering College, Chennai, Tamilnadu India- 600044[2]
Associate Professor, Department of Computer Science and Engineering,
Koneru Lakshmaiah Education Foundation, Vaddeswaram, India, Andhra Pradesh[3]
Associate Professor and Head of the Department, Department of Electronics and Communication Engineering,
Loyola Institute of Technology & Science, Kanyakumari-629302.Tamilnadu, India[4]
Professor, Faculty of Informatics and Computing, UniSZA University, Malaysia[5]
Department of Computer Science, College of Science and Arts in Qurayyat, Jouf University, Saudi Arabia. Information System
Department, Faculty of Computers and Information, Assiut University, Assiut, Egypt[6]

*Abstract*—**Improving medical image quality is essential for accurate diagnosis, treatment planning, and ongoing condition monitoring. A crucial step in many medical applications, the restoration of damaged input images tries to retrieve lost high-quality data. Despite significant advancements in image restoration, two major problems still exist. First, it's important to preserve spatial features, although doing so frequently results in the loss related data. Second, while producing linguistically sound outputs is important, location accuracy can sometimes suffer. To overcome these issues and improve medical imaging, the Multi-Scale Deep Learning-based Recurrent Neural Network (MSDL-RNN) is offered in this paper. The model makes use of various scales during building, in contrast to standard RNN-based techniques, which generally use both full-resolution and gradually reduced-resolution approximations. This multi-scale approach uses deep learning to address problems including noise reduction, defect elimination, and increase of overall image quality. Artificial Bee Colony Optimization is employed for efficient segmentation. By combining local and global data, the MSDL-RNN technique effectively improves and recovers a variety of medical imaging modalities. It generalizes the optimization strategy for model capacity assurance by incorporating crucial pre-processing methods targeted to various medical image types. The suggested approach was implemented in Python software and has an amazing accuracy of 99.23%, which is 4.33% higher than other existing methods like DesNet, AGNet, and NetB0. This study sets the way for important developments in improving the quality of medical images and their uses in healthcare.**

*Keywords*—*Multi-Scale Deep Learning (MSDL); Recurrent Neural Network (RNN); deep learning; medical image; Artificial Bee Colony (ABC)*

## I. INTRODUCTION

A critical step in image processing is the restoration procedure, which seeks to extract high-quality data from a broken or corrupted input image [1]. It uses various techniques and algorithms that examine the data at hand and try to restore the image to its initial condition or enhance its quality. Image restoration is necessary in various contexts, such as imagey with digital cameras, images from satellite surveillance systems and healthcare imaging. The restoration method aims to improve image information, decrease noise and artifacts, and produce attractive and educational images. It utilizes cutting-edge algorithms for image processing and machine learning approaches. The need for high-quality visual content is driving more studies into creating cost-effective and successful restoration techniques. Moreover, image deterioration of different degrees happens frequently due to the acquisition process due to the camera's physical constraints because of challenging illumination circumstances [2]. For example, mobile phone cameras have a tiny detector, wide opening and little range in dynamic. As a result, they frequently generate low-contrast images that are noisy. Comparable to how images are taken in poor illumination can appear excessively dark or excessively bright. Recovery of the distinctive, clear image from its damaged dimensions is the goal of image restoration. Because of the many potential answers, the opposite issue is poorly presented.

Deep learning skills utilization in medical tomography has recently received a portion of interest in image enhancement. One of the challenges that numerous scholars are now interested in is how to identify and split grazes that appear on healthcare images mechanically. Medical image enhancement is essential for several clinical uses because it makes it possible to analyze structures of the body and diseased regions accurately and quickly [3]. According to research, U-Net has displayed exceptional achievement in healthcare image breakdown through various imaging techniques, including magnetic resonance imaging (MRI), computed tomography (CT), ultrasound, and others. The effectiveness of it can be due to the network's capacity to precisely differentiate among

various kinds of tissues, tumours or organs by learning a hierarchical structure of healthcare images. Nevertheless, image restoration (IR), which has a significant practical value in numerous low-level vision software, has proven to be an ongoing problem [4]. Image restoration generally aims at restoring the hidden clear image x from its deteriorated measurement y = T (x) + n, where T is the noise-irrelevant degrading procedure and n is believed to be additive white Gaussian noise (AWGN) with standard deviation. Furthermore, one can obtain distinct IR assignments by defining various degrading procedures.

Consequently, the purpose of numerous image processing issues, such as super-resolution, deblurring, inpainting, colorization, and compression detecting, is to reconstruct an image from relatively noisy information provided by a known linear deterioration pattern [5]. These issues are examples of linear inverse issues. Employing sets of the initial and damaged images, end-to-end supervised training of neural networks can be utilized for image restoration for a particular degrading paradigm. Nevertheless, versatility is frequently needed in practical applications, such as medical imaging, to handle numerous, endless deterioration patterns. Because they can adjust to the particular issue without re-training, unsupervised techniques based on learned priors may be preferable where the deteriorating concept is initially unknown and employed throughout deduction. Considerably, the collection of all essential info from at minimum two images and the basic creation is alienated into fewer image pixels, characteristically into a solitary one, to create the image's standard and decrease repetition, refining all the basic features of the medical image that is second-hand for investigating all medical problems. It is known as a clinical indication combination cycle. These regions are cast-off to switch to the combined phase. The stuffing by the watersheds computation for these sub-images represents determining the regions at individual levels [6]. This watershed computation has become utilized for completing the image separation to maintain the basic enumeration.

Nevertheless, with the introduction of modern technology into the medical industry, medical image enhancement techniques have received a lot of interest. A surgeon needs improved medical images to help with diagnostic and analysis due to noise, other data-gathering equipment, lighting circumstances, etc. It commonly degrades the quality of medical images [7]. Additionally, the major goals of healthcare image improvement are to address issues with a medical image's low brightness and elevated degree of contamination. Moreover, several research efforts have focused chiefly on greyscale and frequency spectrum transformations in healthcare image improvement techniques [8]. Also, Histogram equalization is a widely used technique for image enhancement in the spatial field, while research on the frequency-domain transformation mainly focuses on the Fourier transformation. While most methods for image enhancement are normally used to offer better images for human observers, some are used as an initial processing stage to deliver better images to later techniques for computer-assisted studies. Therefore, the initial category consists of methods for reducing noise, boosting contrary, and sharpening

features. Edge recognition and segmentation of objects for machine learning are the two more methods included in the subsequent type, which largely overlaps with the first [9]. It has been demonstrated that a medical image with a significant contrast can aid in an additional exact valuation of the various tissues in the examined body area.

Therefore, separating the most beneficial data from the processed images is the study's key goal. As a result, many strategies are used to separate the fundamental facts, such as image registration and image fusion [10]. Creating a network of connected images is the goal of image registration. Image registering is also recognized as image merging or pairing and combines more than one image based on how they seem from the outside. Moreover, the healthcare image registration process seeks the ideal spatial transformation assessment that organizes the fundamental physiological frames. Also, healthcare registration of images is used in several healthcare programs, including radiation buildup, tracking of motion, image rebuilding and image navigation. Every procedure performed on an image aims to improve its quality. Because of the issues with the image source of information, there are regular or ad hoc defects and disturbances in the image structure [11]. These flaws and disturbances damage every pixel in the image. For the images to be employed in practice and more intelligible, these flaws must be removed with the use of initial processing techniques.

The key contributions of this research are given below as follows:

- By effectively decreasing noise and maintaining significant image information, the application of a median filter during the pre-processing phase improves image quality and guarantees that the next analysis will benefit from cleaner input data.

- By optimizing the process of locating and isolating regions of interest, the ABC optimization Algorithm is used to image segmentation, enhancing the precision and effectiveness of medical image analysis.

- The GLCM's ability to extract texture features provides insightful information about the structural properties of medical images, enabling more accurate and thorough analysis for diagnostic reasons.

- By using RNN for image classification, the system is able to efficiently classify medical images, which helps with medical condition detection and treatment by using learnt patterns and features. This, in turn, enhances the overall efficiency of the medical image processing pipeline.

This article's remainder is organized as follows: In Section II, a summary of related research is provided. Section III presents the problem statement. The suggested approach's methodology and architecture are explained in Section IV of the article. The findings and subsequent discussion are covered in Sections V and VI, respectively. The conclusion is covered in Section VII.

## II. RELATED WORKS

For historical years, machine learning, especially deep learning, has improved the analysis of medical images said by L. Chen et al. [12]. It takes a lot of labelled information to train an effective deep-learning algorithm. Nevertheless, getting enough annotated images for training is frequently a challenge. The dataset in consideration frequently contains more unlabelled images than tagged ones. Consequently, it is necessary but difficult to improve the efficacy of machine learning models by employing labeled and unlabelled data. Self-supervised learning is one approach to resolving this issue. Existing self-supervised learning techniques that are suitable for medical images are unable to achieve appreciable improvements in performance. They frequently produce very slight benefits as a result. To more effectively utilize unorganized images, researchers offer a new self-supervised learning technique built around background restoration in this research.

In demand to create novel medical image processing methods, deep learning has involved much study care, as said by X. Chen et al. [13]. Deep learning-based replicas have been confirmed to be tremendously active in a series of medical imaging activities that permit disease detection. Several investigations have remained completed in the last five years with the goal line of solving this tricky. Researchers analysed and synthesized this current research to present an in-depth review of the use of deep learning techniques in various medical imaging analysis challenges in the present research. Moreover, researchers concentrate in particular on the furthermost fresh growths and achievements of state-of-the-art unsupervised and semi-supervised deep learning in the analysis of medical images that are outlined according to many different application instances, spanning separation, identification, and registration of images. Furthermore, researchers discuss the main technological difficulties and offer potential fixes for future research projects.

In his paper, Ahuja [13] said that following the combination of machine learning and deep learning methods, medical imaging has undergone a substantial revolution that has resulted in the creation of smart imaging equipment. These devices use artificial intelligence to improve the precision, effectiveness, and comprehension of healthcare images. To help with evaluation and therapy organizing, machine learning techniques enable the computerized evaluation of healthcare images, encompassing the process of segmentation, categorization and registrations. Convolutional neural networks specifically have demonstrated outstanding results in applications like segmentation based on semantics, recognizing objects, and image classification. The developing subject of generative adversarial networks shows potential for exceptional case synthesizing and data augmentation. It is necessary to handle issues like data accessibility and interpretability. The primary problem of this is quality control and governance.

J. Liu et al. [14] discussed in his paper that by taking into account the particular needs of medical image security for the injury regions, a new zero-watermarking method for healthcare images that utilize DTCWT-DCT has been suggested to address safety concerns with healthcare images that are saved and sent in the cloud. Initially DTCWT is applied to healthcare images. A graphical feature vector consisting of healthcare images that resist geometrical attacks is also obtained from the low-frequency DTCWT parameters. The logistic map is then used with the idea of zero-watermarking to secure the watermark. Based on this, the encoding and retrieval of the watermark is implemented by fusing conventional watermarking techniques with random data encryption cryptography and third-party notion. In contrast to conventional watermarking methods, the suggested approach using DTCWT-DCT does not involve deliberately selecting the region of interest, therefore resolving the quick issue associated with integrating the watermark. Additionally, the incorporated watermark is a zero-watermarking, which leaves the genuine healthcare images unchanged. Logistic Map handles the chaotic encrypting processes, which might increase the watermark's safety.

The main medical imaging (MI) issue is the image denoising discussed by Elhoseny and Shankar [15]. The most difficult part of denoising an image is preserving the data-bearing surface and borders while improving Peak Signal to Noise Ratio (PSNR). In this research, the innovative Bilateral Filter (BF) optimization-based clarifying technique is engaged in deliberation for the MI noise reduction process. The conclusion to select the best variables, i.e., Gaussian and spatial weights, is inclined by how the denoising procedure is passed out. These variables are designated in this case using the DF and MFF algorithms. PSNR and VRMSE are used to determine this variable. The denoised image is additionally classified as normal or abnormal using a CNN classifier with a higher classification rate.

Protecting the authenticity and validity of healthcare images is crucial in telehealth said by X. Liu et al.[16]. Two methods, region of interest (ROI) lossless and reversible watermarking, concentrate on these. Nevertheless, the latter pose safety hazards by splitting the image geographically for watermark implantation and distorting diagnostic by altering the region of no interest (RONI). When ensuring image authenticity, the latter lacks a dependable restoration mechanism for the altered portions. In this research, an innovative and resilient reversible watermarking approach is developed to deal with these problems. To prevent distortions in assessment, this approach uses a reversible watermarking technique that employs recursive dither modulation (RDM).

Suri et al. [17] discussed in his paper that radiology is one area of healthcare where artificial intelligence (AI) has made inroads. Since its discovery, the very aggressive coronavirus disease 2019 (COVID-19) has spread to more than ten million individuals. As of July 1st, 2020, it caused more than 500,000 fatalities. Nearly 28,000 publications concerning COVID-19 have been released since the epidemic started, but few have examined the use of radiography and machine learning in COVID-19 patients, particularly those with multiple medical conditions. The four different routes that can result in brain and heart damage after a COVID-19 illness are first described in this research. According to probabilities calculated from COVID-19 symptomatic research, the survey also provides information about the part radiology can play in the

management of comorbidity people. The main objective of this research is the implementation of image-based AI to describe the structures of a COVID-19 patient and categorize the degree of severity of their illness. As the global epidemic spreads and nation's worldwide struggle with limited healthcare facilities for surveillance and treatment, image-based AI is more crucial than before.

Wang et al. [18] discussed in his paper that a coloured image rectification approach that utilizes non-linear functionality conversion by the brightness-reflection model and multi-scale concept is presented to enhance the flexibility of visualization in images with low illumination. The initial RGB image is altered to HSV color space before extracting the illuminating part of the illustration utilizing the multi-scale Gaussian function. The setting parameters of the image-enhancing mechanism are then adaptively adjusted depending on the spatial distribution characteristics of the lighting elements to produce two images. The correction mechanism is then built using the Weber-Fechner law. The features underlying the two images are then extracted using an image fusion approach. The suggested technique, when compared to the traditional method, can enhance an image's total contrast and brightness while lessening the effects of unequal brightness. The improved images are crisp, inevitable and precise. This paper's lack of brightness is its fundamental flaw.

Greater detail is available in high-quality MR images, enabling accurate diagnosis and statistical image analysis [19]. A deep CNN has demonstrated its potential capacity for super-resolution imaging given LR images. The underlying texturing of various sizes, the highly correlated edges, and the backdrop that is less instructive are a few visual traits that the LR MR images often have in common. Although the backdrop is smoother, multiple scales structural details are instructive for image restoration. The majority of earlier CNN-based SR techniques treat all spatially pixels identically and employ an individual field of reception. For superior MR image SR, it fails to detect the full space and extract a variety of attributes from the input. To solve these issues, a wide weighted attention multi-scale network (W2 AMSN) is suggested for precise MR image SR. On the opposite, the broad multi-scale branching may be used to extract the characteristics of various sizes. On the contrary, in order to continually calibrate feature reactions, a non-reduction attentiveness technique. This focus maintains ongoing cross-channel contact and concentrates on areas that are more relevant. The accessible weighting factors, however, dynamically combine recorded characteristics. A recurrent foundation and a global system for attention are used to incorporate the encapsulated W2AMSB numerous evaluations and a variety of research on ablation demonstrate the usefulness of the suggested W2 AMSN, that outperforms cutting-edge techniques on the majority of common MR image SR standards both numerically and subjectively. On actual MR images, this method still provides greater accuracy and flexibility.

SISR has been shown to greatly benefit from CNN [20]. Previous studies, nevertheless, have not fully used multi-scale characteristics and have disregarded the inter-scale relationship among various up sampling parameters, leading to poor results. It is devoted to mining image characteristics and

discovering the inter-scale relationship among various expanding variables rather than only raising the level of the network irrationally. A MDCN is used to do this, which delivers outstanding efficiency with fewer settings and shorter processing time. DRB, HFDB, and MDCBs make up MDCN. They include DRB, which aims to reconstruct SR images with various up sampling variables within a single model, and MDCB, which concentrates on automatically recalibrating channel-wise feature reactions in order to accomplish feature the distillation process. It's important to note that each of these modules has autonomous operation. To enhance the accuracy of the model, these components may be selectively integrated into any CNN model. Numerous investigations demonstrate that MDCN performs competitively in SISR, particularly when it comes to reconstruction tasks involving numerous up sampling values. On GitHub, the code is available under the name MIVRC/MDCN-PyTorch.

The interpretation of medical images has greatly increased in recent years due to machine learning, especially deep learning, but labelled data is still hard to come by. Researchers have developed a unique self-supervised learning method based on backdrop restoration to overcome this problem. Additionally, researchers have studied state-of-the-art unsupervised and semi-supervised deep learning approaches. Deep learning has proven crucial in a variety of medical imaging applications, including illness diagnosis. Meanwhile, the combination of deep learning and machine learning has produced smart imaging devices that increase the precision and effectiveness of the interpretation of medical images. Medical image security is an issue, and to improve image safety, a zero-watermarking technique utilizing DTCWT-DCT has been developed. Moreover, image denoising is crucial for medical imaging, and noise reduction is achieved using an optimization-based technique based on bilateral filters. Furthermore, maintaining the integrity of images is essential in telehealth, and to avoid distortions, a robust solution to reversible watermarking has been created. Particularly in the context of COVID-19, AI has advanced significantly in radiology, with image-based AI being essential for controlling the severity of sickness. Deep CNNs have demonstrated potential for super-resolution imaging, and an inventive method of image correction improves image visibility. Finally, a multi-scale network method that offers faster processing times and more efficiency is suggested for image super-resolution. In a number of respects, these developments are spearheading the revolution in medical imaging and healthcare.

## III. PROBLEM STATEMENT

The above discussed literatures states that, in healthcare, the effectiveness of medical imaging is crucial for precise diagnosis, treatment planning, and continuing condition monitoring. Despite significant advancements in image restoration methods, there are still two significant problems. First, it is necessary to protect important spatial elements without losing context-related data, which is frequently lost during restoration methods. Second, while maintaining exact location precision might be challenging, creating linguistically sound outputs is essential. This paper presents an MSDL-RNN to overcome these problems and enhance medical imaging.

The MSDL-RNN uses various scales during model development, in contrast to typical RNN-based techniques that frequently depend on both full-resolution and gradually reduced-resolution approximations. A comprehensive solution to increase medical image restoration and enhancement across many modalities is provided by this ground-breaking multi-scale technique, which efficiently uses deep learning capabilities to address issues including noise reduction, defect elimination, and overall image quality enhancement [21].

The selection of the suggested approach is supported by a number of elements that make it extremely suitable for handling the particular issue at hand. First off, the segmentation process is made more flexible and precise by using the ABC optimization method. This is especially important for medical image analysis, since precise identification of regions of interest is critical. Second, applying a median filter during the pre-processing phase guarantees that noise is efficiently minimized, maintaining crucial image features and enhancing the quality of the input data a feature that is especially helpful for medical images that are frequently tainted by noise. Moreover, the application of the GLCM for feature extraction yields a thorough

comprehension of the textural and structural characteristics present in the images, which is an essential component of medical image analysis. However, the constraints of current approaches, such as basic pre-processing's limited noise reduction capabilities and classic segmentation techniques' lack of flexibility, make them ill-suited for the complexity and requirements of medical image analysis. These drawbacks highlight the need for the integrated approach of the suggested strategy, which combines these deficiencies and makes it a strong option for the given situation.

## IV. PROPOSED ABC-RNN METHODOLOGY

The second dataset for training and testing is the Kaggle dataset. This is employed to show the efficacy of the analysis and to find the diseases in patients. Pre-processing is used to eliminate unwanted noise distortions and improve specific qualities that are essential for the process. Correspondingly, the standard MSDL-RNN technique is employed to restore and enhance the medical image. Furthermore, it is employed to attain a better accuracy value. Fig. 1 shows the architecture of the proposed MSDL-RNN.
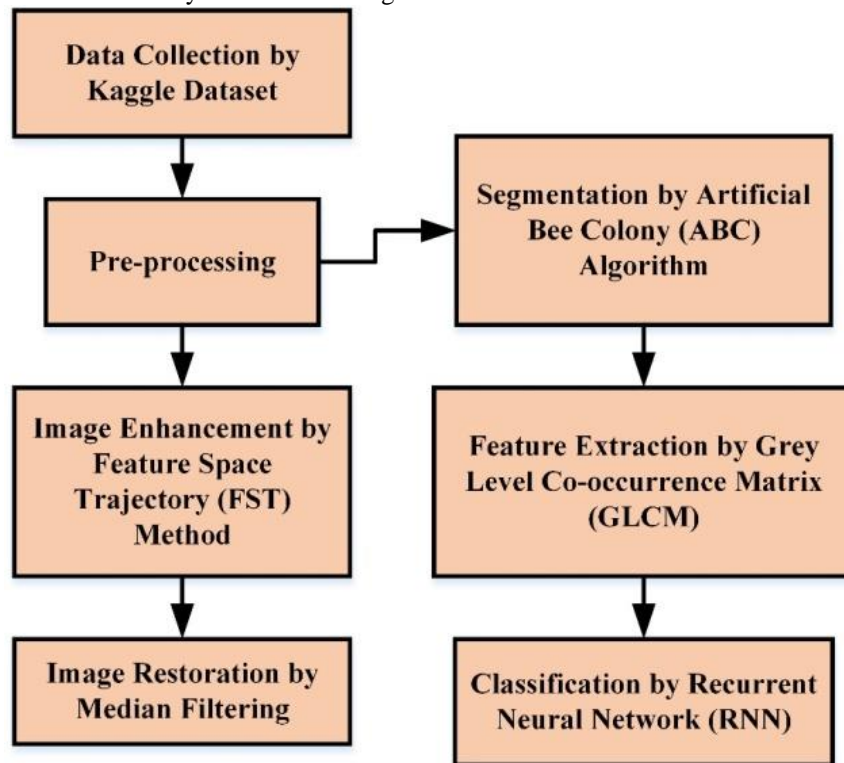


Fig. 1.   Proposed ABC-RNN architecture.

### A. Data Collection

The dataset used here is the Kaggle dataset [22]. Nearly, 10,000 datasets are used. From this, 50% of the datasets are second-hand for the training process and the other 50% for the testing process.

### B. Median Filter for Pre-processing

Pre-processing is done to remove unwanted noise, eliminate defects, and ensure the comprehensive quality of

images. Here, pre-processing is used to improve and improve the image quality. The image enhancement is done by Feature Space Trajectory (FST) method. The route or trajectory data points taken when traversing the space of features is referred to as the FST   [23]. The space determined by the data's characteristics or qualities is referred to as feature space in the arenas of machine learning and data analysis. The exact location of every data point in the space of features is determined by the set of value features that represent it. And

also, the image restoration is done by Median filtering [24]. The steps and equations of the median filtering are given below:

Step 1: Give an input image that is represented as J

Step 2: The image's channels is divided, and the highest and lowest P pixels in every channel are determined in (1) and (2)

$$minimum = minimum_{(i,j)} P(i,j) \qquad (1)$$

$$maximum = maximum_{(i,j)} P(i,j) \qquad (2)$$

Step 3: The channel of the image is non-linearly modified as seen below in (3)

$$P_1(i,j) = minimum - (maximum - minimum) \times \left( \frac{(P(i,j) - minimum)}{maximum - minimum} \right)^{\beta} \qquad (3)$$

The change in wavelength is comparable to the beta transformation but is not the same. The result of the transformation, which is the input image, does not change the image when $\beta=1$ is applied. When $\beta \neq 1$, the transformation may extend or conceal the image's pixel values, boost contrast and recover high-frequency elements that disappeared because of border data and the distance, among other capabilities. When $\beta<1$, extending the low-pixel frequency band and decreasing the high-pixel frequency band is possible In this instance, it is possible to efficiently recover the minute details of the deeper portion of the image while also improving the local brightness of the darker region of the image and the effect of the stronger lighting on the image. When $\beta > 1$, low-pixel data can be muted by stretching the spectrum of high-pixel data. In this scenario, it is possible to efficiently recover the minute details of the brightest portion of the image by increasing the local brightness of the brightest section. So, grounded on the image's circumstances that need improvement, one can select the c value. Stronger lighting will result in poorer image pixel values.

Step 4: The image was transformed logarithmically, as displayed in the resulting manner given below in (4),

$$P_2 = log(P_1 + n) \qquad (4)$$

The alteration can broaden the image's low-pixel frequency spectrum, boost the darker image's contrast, which helps to recover the darker image's features more effectively and is more suitable for outdoor locations with lower light levels. Nevertheless, logarithmic treatment significantly diminishes the image's luminosity and reduces the high-pixel frequency. To compensate for this, the image's luminosity can be somewhat improved by setting an even amount preceding the logarithmic adjustment.

Step 5: The image is normalized to have pixel values that range from 0 to 255. Eq. (5) provides the particular conversion.

$$P_3 = \frac{(P_2 - minimum) \times 255}{(maximum - minimum)} \qquad (5)$$

## C. Segmentation using Artificial Bee Colony Optimization Algorithm

Segmentation has become more important in various aspects of image processing, especially classification, image recovery and object recognition [25]. It is an essential step in numerous applications. The suggested approach employs Artificial Bee Colony Optimisation (ABC) to discover similar regions and appropriately inspect every section once images have been segregated following the pre-processing stage.

The ABC algorithm, which stands for Artificial Bee Colony, is an optimization method that mimics the honey bee's feeding behavior and has been effectively used to solve several real-world issues. The class of algorithms for swarm intelligence includes ABC. A group of honey bees known as a swarm can work together to complete activities effectively [26]. Additionally, the ABC method has three different kinds of bees: working bees, observers and scouting bees. The recruited bees searching for food nearby the food resource in their memories while informing the spectator bees about these food sources. Despite the food resources discovered by the worker bees, the onlooker bees frequently select the best ones. The likelihood that the onlooker bees will select the nourishment basis with better quality (fitness) is much greater than the likelihood that they would choose the one with a lower level of quality. Scout-type bees are derived from a trivial number of worker bees that leave their nourishment foundations and look for new ones. The employed bees make up the initial part of the swarm in the ABC algorithm, and the onlooker bees make up the second half. The total number of solutions in the swarm is equivalent to the number of engaged bees or observers.

This study aims to investigate the effects of ABC parameters in a Multi-Scale Deep Learning-Based Recurrent Neural Network on Medical Image Restoration and Enhancement. ABC is an optimization method that carefully adjusts the hyper parameters of the network. The model's overall performance is significantly impacted by the meticulous selection of ABC parameters, such as colony size, convergence criterion, and exploration rate. When these parameters are optimized with expertise, the network is able to perform very well in the complex field of medical image restoration and enhancement, leading to better denoising and sharpening of medical images. The careful choice of ABC parameters results in improved image quality as well as increased network accuracy when it comes to medical image restoration. This significantly increases the Multi-Scale Deep Learning-Based Recurrent Neural Network's overall efficacy in the field of medical image processing.

The ABC algorithm creates a starting population with a uniform distribution of randomness. Every solution $y_j$ (j = 1, 2..., SN) in this group has a solution number (SN). The formula for ABC optimization is given in (6) below:

$$y_j^i = y_{minimum}^i + random\,(0.1)\left(y_{maximum}^i - y_{minimum}^i\right), \forall\, i = 1,2,...V \qquad (6)$$

Where, $y_j$ stands for the $j^{th}$ source of nourishment in the starting community; $y_{maximum}^i$ and $y_{minimum}^i$ are the boundaries of $y_j$ in the $i^{th}$ route.

According to the nectar's efficiency data, the hired bee stage improves the hired bee's present strategy. This also comprises modifying the location of the nourishment basis according to its output and its calculation is given in (7). If it is discovered to be smaller than the previous one, the food sources with significant quantities are upgraded; otherwise, they are eliminated.

$$u_{ji} = y_{ji} + \emptyset_{ji}(y_{ji} - y_{li}) \qquad (7)$$

Where, $\emptyset_{ji}(y_{ji} - y_{li})$ is denoted as the step size; $\in \{1,2, \ldots SN\}$ , $i \in \{1,2, \ldots V\}$ are represented as the indices that are chosen randomly; $\emptyset_{ji}$ belongs to the range [-1,1].

The observer bee phase evaluates the collective nectar fitness and positional data provided by worker bees and according to the fitness chance and it selects the optimum course of action. The location of the worker bees is updated by the greater fitness chance and is given in (8) below:

$$q_j = \frac{g_j}{\sum_{i=1}^{SN} g_i} \qquad (8)$$

Where, $g_j$ denotes the $j^{th}$ fitness solution.

The hunter-bee phase starts looking for additional food sources when the food supply is depleted. This condition occurs if a source of nourishment disappears and its location has not been verified for the required number of cycles. A scout bee begins creating novel food sources in the surroundings and has a connection with discarded food. Nevertheless, in its simplest form, the ABC approach struggles with efficiency when handling challenging issues with a large search area. It demands a lot of fitness assessments and gets caught in regional minima. ABC also excels in discovery but struggles with the harvest. Many researchers were motivated by these flaws to suggest ABC versions for resolving various actual, empirical restrictions.

### D. Feature Extraction by GLCM

Feature extraction is selecting and highlighting raw data's most important information or characteristics [27]. It transforms the basic data into a more streamlined and practical form that might be used for tasks demanding simulation or further analysis. In machine learning and pattern recognition software, feature extraction is widely utilized to enhance computational effectiveness and presentation. This research uses a Gray-Level Co-Occurrence Matrix (GLCM) to extract features. In extracting features, the initial information is changed into mathematical topography that is devoid of any construction of alterations in the strange datasets, and its features are based on its pixels. It employs multiple parameters, such as energy, correlation, contrast, homogeneity, entropy, etc., which are second-order image characteristics to remove the statistically significant texture characteristics from the image.

*1) Energy:* The squares with regularly greater grayscale and erratic image concentration standards are summated to generate energy. In (9), the energy formula is shown.

$$\text{Energy} = \sum i \sum j \{N(i,j)\}^2 \qquad (9)$$

Here, N is denoted as the images; (i, i) is represented as the squares of the image.

*2) Contrast:* The regional intensity of an image is calculated using characteristics and is expected to be lower when the value of attentiveness is even. The comprehensive grayscale data of the original image is then displayed and its calculation is given in as (10).

$$\text{Contrast} = \sum_{x=0}^{H_j} x^2 \left\{ \sum_{i=1}^{H_j} \sum_{j=1}^{H_j} N(i,j) \right\} \qquad (10)$$

Here, H stands for the grayscale images; N is represented as the images; (i, j) is represented as the square of the greyscale image.

*3) Correlation:* By using the correlational features, it is feasible to adjust the mathematical links among the parameters and the inverse relationship of the grey levels on pixels. Its calculation is indicated in (11).

$$\text{Correlation} = \frac{\sum_i \sum_j (i,j) N(i,j) - \mu_p \mu_q}{\sigma_p \sigma_q} \qquad (11)$$

The images' $\mu_p$, $\mu_q$, $\sigma_p$, and $\sigma_q$ values for the average and the standard deviation are denoted as row and column correspondingly.

*4) Entropy:* The anticipated substantial amount of the randomness of the distribution of grey levels is entropy and its calculation is shown in (12).

$$\text{Entropy} = - \sum_i \sum_j N(i,j) \log(N(i,j)) \qquad (12)$$

---

**Algorithm 1:** *Pseudo code for ABC Optimization*

The problem should be defined initially.
Prioritize the ABC algorithms parameters.
Develop the colony of the worker bees.
Then the estimation of all the bee's fitness values should be done.
**Repeat** the process
M=0
**Repeat** the process
(l=a result in the locality of j)
($\emptyset$ = a random number in the range $[-1,1]$)
Develop novel results using Eqn. (7)
Then the process of greedy selection is applied.
The likelihood functional values are estimated using Eqn. (8)
Next the onlooker bees are assigned.
**Do** $\forall$ onlooker bees.
Again, the process of greedy selection is applied.
If the fitness worth of the onlooker bees is lesser than the fitness worth of the worker bees
Exchange it with the worker bees.
**End**
**End**
**If** the fitness of the best onlooker bees is lesser than the fitness of the best bee
Exchange all with the superior results.
**End**
M=M+1
**Until** (M=Number of the worker bee)
Define the rejected result with Eqn. (6)
**If** the scout bees result is superior to the worker bees result, replace it with the scout bees' result.
**Until** the maximum iteration

---

### E. Classification using RNN

The results from positive nodes can impact upcoming inputs to exact similar nodes via a recurrent neural network (RNN), an intimate of artificial neural networks whose interconnections among vertices can create a loop [28]. It can show continuous fluctuation. RNNs originated from feedforward neural networks and can handle classifications of inputs of various lengths by using their internal state. They can be used for applications like linked, not segmented recognition of handwriting or speech. A recurrent neural network describes networks with an infinite impulse response. The behavior of RNNs is temporally unpredictable. The architecture of RNN is shown in Fig. 2, followed by the algorithm of ABC optimization is given below. Fig. 3 displays the illustration of the proposed MSDL-RNN technique.
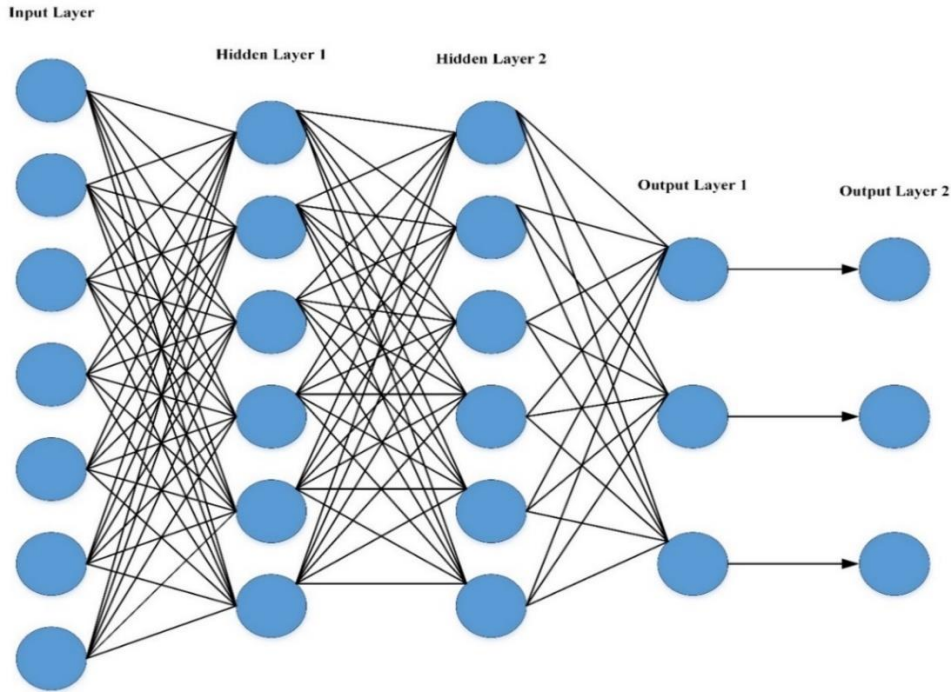


Fig. 2. Architectural diagram of RNN.
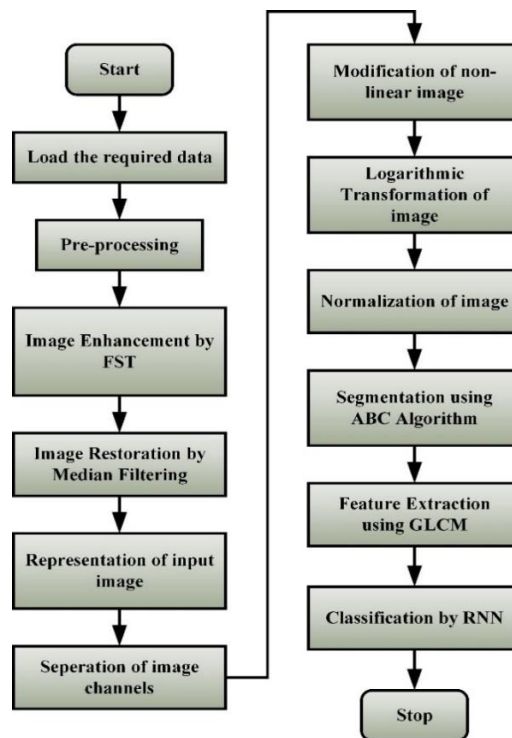


Fig. 3. Flowchart of proposed MSDL-RNN.

## V. RESULTS

The planned method has been investigated by using some datasets. Here, the Multi-Scale Deep Learning Based Recurrent Neural Network is used in this research for the procedure of image restoration and image enhancement. The description of the planned model is discussed by some parameters such as Accuracy, Recall, Precision, F1 Score, MSE, PSNR, and SSIM.

### A. Performance Metrics Evaluation

*1) Accuracy:* The easiest metric to comprehend is accuracy, which measures how many examples in a dataset have been correctly categorized as a percentage of all instances. It offers a broad gauge of overall accuracy. The accuracy calculation is given in (13) below:

$$Accuracy = \frac{(TP+TN)}{(TP+TN+FP+FN)} \qquad (13)$$

*2) Precision:* The percentage of cases that were correctly foretold as positive compared to every instance is what precision measures. It gauges the framework's capacity for avoiding erroneous positive results. For precision, use the formula which is shown in (14) below:

$$Precision = \frac{TP}{(TP+FP)} \qquad (14)$$

*3) Recall:* Recall counts how many advantageous circumstances were properly predicted out of all the favorable instances. It measures how well the model can find every instance of positivity. The recall equation is given in (15) below:

$$Recall = \frac{TP}{TP+FN} \qquad (15)$$

*4) F1-Score:* Precision and recall are harmonically summed to produce the F1 score. It yields a single value by combining the two metrics, giving a fair assessment of the efficacy of a model. The formula for F1-Score is given in (16) below:

$$F1 - Score = 2 \times \frac{(Precision \times Recall)}{(Precision + Recall)} \qquad (16)$$

*5) Mean Square Error (MSE):* An average square variance among the values of the pixels of the underlying and altered images are calculated by MSE. Lower scores suggest higher levels of quality in the restoration or enhancement process, and it estimates the overall appearance reconstruction inaccuracy. The calculation for MSE is given in (17) below:

$$MSE = \frac{1}{MN}\sum_{n=0}^{M}\sum_{m=1}^{N}[\hat{g}(n,m) - g(n,m)]^2 \qquad (17)$$

Where M and N are represented as the total number of pixels in the images; the $\sum$ is represented as the summation; $\hat{g}(n,m)$ is represented as the original pixel value image; $g(n,m)$ is represented as the pixel value of the processed image.

*6) Peak Signal Noise Ratio (PSNR):* The PSNR scale gauges the difference between the highest possible signal power and the strength of corrupted interference. Contrasting the initial and modified images is a common way to gauge how well the image restoration or enhancement techniques perform. Greater PSNR readings indicate greater image quality. The calculation of PSNR is given in (18) below.

$$PSNR = \frac{10 \, log_{10} \, (peak \, value)^2}{MSE} \qquad (18)$$

*7) Structural Similarity Index Metric (SSIM):* A statistic called SSIM evaluates how structurally two images are similar. It verifies perceived image quality by considering contrast, brightness, and structural data. The range of the SSIM is 0 to 1, with readings nearer to 1 and that suggests higher resemblance. The calculation of SSIM is given in (19) below.

$$SSIM = [l(x,y)]^\alpha \times [c(x,y)]^\beta \times [s(x,y)]^\gamma \qquad (19)$$

Where $l$ is represented as the luminance, c is represented as the contrast and s is represented as the structure.
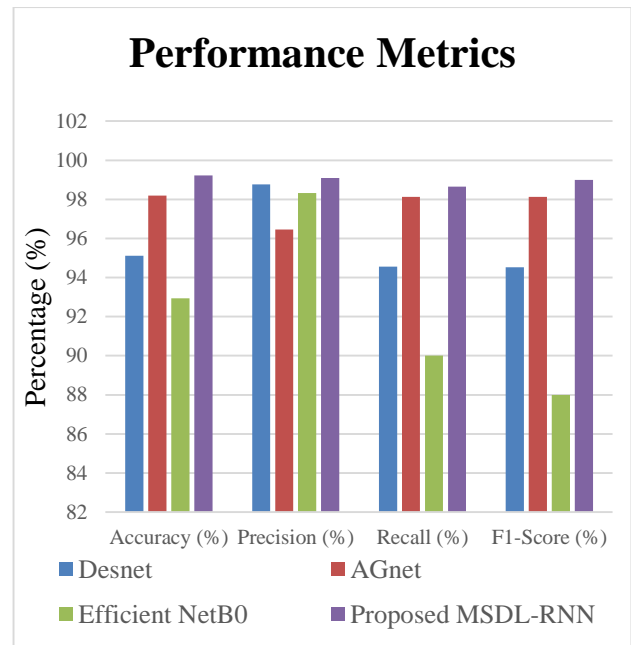


Fig. 4. Comparison graph of accuracy.

The Table I presents a comparative examination of the accuracy, precision, recall, and F1-score performance measures of several approaches and it is depicted in Fig. 4. It analyse four approaches: Desnet, AGnet, Efficient NetB0, and Proposed ABC-RNN. Desnet obtains an F1-score of 94.53%, an accuracy of 95.11%, a precision of 98.77%, and a recall of 94.56%. With precision and recall both above 96% and high accuracy of 98.20 per cent, AGnet has an F1-score of 98.13%. Efficiency NetB0 has a 92.93% accuracy, a 98.32% precision, a 90% recall, and an 88% F1-score. With extraordinary accuracy of 99.23%, precision of 99.10%, recall of 98.65%, and an F1-score of 99%, the proposed ABC-RNN approach beats others.

TABLE I. COMPARISON OF PERFORMANCE METRICS

| Method | Accuracy (%) | Precision (%) | Recall (%) | F1-Score (%) |
|---|---|---|---|---|
| Desnet [29] | 95.11 | 98.77 | 94.56 | 94.53 |
| AGnet [30] | 98.20 | 96.45 | 98.13 | 98.13 |
| Efficient NetB0 [31] | 92.93 | 98.32 | 90 | 88 |
| Proposed MSDL-RNN | 99.23 | 99.10 | 98.65 | 99 |
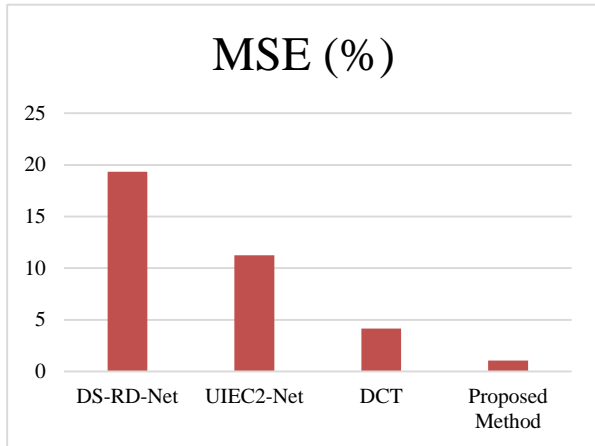


Fig. 5. Comparison graph of MSE.

Table II and Fig. 5 show the evaluation and performance estimation of MSE. When associating the MSE of the planned technique with the following three existing methods, i) DS-RD-Net [32] ii) UIEC2-Net [33] iii) DCT [34], the proposed MSDL-RNN algorithm produces a lower MSE of about 1.04.

TABLE II. COMPARISON TABLE OF MSE

| Method | MSE (%) |
|---|---|
| DS-RD-Net [32] | 19.34 |
| UIEC2-Net [33] | 11.26 |
| DCT [34] | 4.15 |
| Proposed Method | 1.04 |
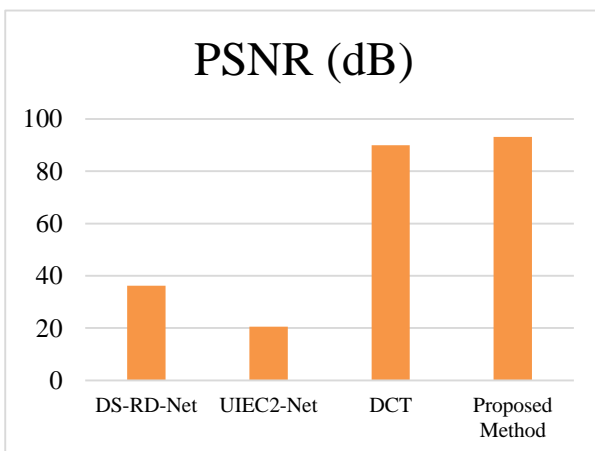


Fig. 6. Comparison graph of PSNR.

Table III and Fig. 6 show the evaluation and performance estimation of PSNR. When associating the PSNR of the planned technique with the following three existing methods, i) DS-RD-Net [32] ii) UIEC2-Net [33] iii) DCT [34], the proposed MSDL-RNN algorithm produces a greater PSNR of about 93.12 dB.

TABLE III. COMPARISON TABLE OF PSNR

| Method | PSNR (dB) |
|---|---|
| DS-RD-Net [32] | 36.21 |
| UIEC2-Net [33] | 20.54 |
| DCT [34] | 89.97 |
| Proposed Method | 93.12 |
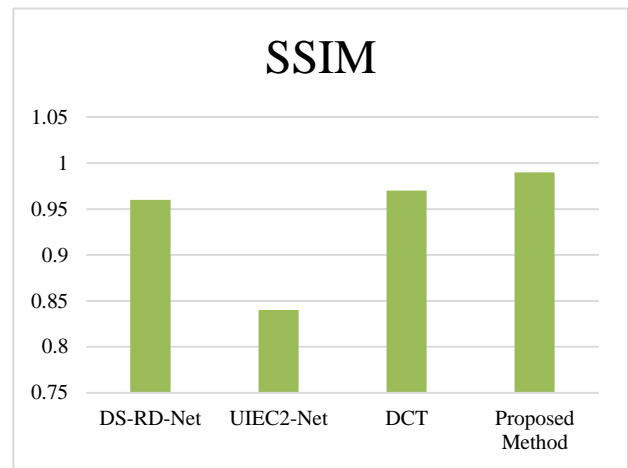


Fig. 7. Comparison graph of SSIM.

Table IV and Fig. 7 show the evaluation and performance estimation of SSIM. When associating the SSIM of the planned technique with the following three existing methods, i) DS-RD-Net [32] ii) UIEC2-Net [33] iii) DCT [34], the proposed MSDL-RNN algorithm produces a greater SSIM of about 0.99.

TABLE IV. COMPARISON TABLE OF SSIM

| Method | SSIM |
|---|---|
| DS-RD-Net [32] | 0.96 |
| UIEC2-Net [33] | 0.84 |
| DCT [34] | 0.97 |
| Proposed Method | 0.99 |

## VI. DISCUSSIONS

The efficiency of the recommended MSDL-RNN strategy is higher when compared to earlier-used methods like Desnet, AGnet, and Efficient NetB0. The proposed methods' MSE value range is lesser than the other DS-RD-Net, UIEC2-Net and DCT methods values. The PSNR and SSIM values range higher than the other DS-RD-Net, UIEC2-Net and DCT methods. The anticipated technique's accuracy is greater than the efficacy determined by MSDL-RNN alone. The accuracy level achieved by utilizing this model is 99.23%. This

suggests the multi-scale deep learning-based recurrent neural network will enhance and restore medical images. The Kaggle dataset was utilized in this instance. The pre-processing approach is employed to lessen noise, eliminate corrupted images and enhance the superiority of the images. The FST technique is used to improve the image, and median filtering is used to restore it. After that segmentation is completed. ABC optimization performs segmentation, splitting an image or a bigger dataset into unique, significant segments or areas. The GLCM approach is used for feature extraction, choosing and emphasizing the most crucial details or traits from raw data. The classifying procedure is finished at that point. A machine learning model must first be trained to classify or categorize data into pre-set categories or groups. RNN handles it. The ABC algorithm's fictitious code is then presented. It now gets to the section where results and discussions take place. The proposed method is shown to have superior outcome statistics than every other approach when accuracy, recall, precision, f1-score, MSE, PSNR and SSIM are evaluated. The research then presented its findings and plans for the future.

## VII. CONCLUSION AND FUTURE WORK

The findings of this study underline how crucial it is to improve medical image quality for precise diagnosis, treatment planning, and ongoing condition monitoring in healthcare applications. By restoring lost high-quality data, the restoration of damaged input images constitutes a crucial step in accomplishing these goals. Despite substantial advancements in the field of image restoration, this work addresses two enduring problems. An innovative response to these problems is provided with the launch of the MSDL-RNN. MSDL-RNN differs from traditional RNN-based algorithms that depend on both full-resolution and gradually reduced-resolution approximations by using a multi-scale approach during model development. Deep learning is used in this breakthrough to efficiently solve problems including noise reduction, defect eradication, and the improvement of overall image quality. The MSDL-RNN technique's combination of local and global data enables the enhancement and recovery of a variety of medical imaging modalities. Despite these encouraging results, a noteworthy drawback of this work is that it largely concentrates on the improvement of image quality, leaving opportunity for potential future research in real-time applications and computing efficiency. Future studies should focus on reducing the processing requirements of the model to enable a smooth incorporation into clinical operations. The results of this study set the way for substantial developments in the field of medical imaging by providing a solid answer to problems relating to image quality improvement. The results of this study offer significant potential for enhancing patient care, diagnostic precision, and the general usability of medical images in healthcare applications, since the healthcare sector continues to rely heavily on them.

## REFERENCES

[1] S. Laine, T. Karras, J. Lehtinen, and T. Aila, "High-Quality Self-Supervised Deep Image Denoising," vol. 32, 2019.

[2] S. W. Zamir et al., "Learning Enriched Features for Fast Image Restoration and Enhancement." arXiv, Apr. 19, 2022. Accessed: Jul. 14, 2023. [Online]. Available: http://arxiv.org/abs/2205.01649

[3] X.-X. Yin, L. Sun, Y. Fu, R. Lu, and Y. Zhang, "U-Net-Based Medical Image Segmentation," J. Healthc. Eng., vol. 2022, pp. 1–16, Apr. 2022, doi: 10.1155/2022/4189781.

[4] K. Zhang, Y. Li, W. Zuo, L. Zhang, L. Van Gool, and R. Timofte, "Plug-and-Play Image Restoration with Deep Denoiser Prior." arXiv, Jul. 12, 2021. Accessed: Jul. 14, 2023. [Online]. Available: http://arxiv.org/abs/2008.13751

[5] B. Kawar, M. Elad, S. Ermon, and J. Song, "Denoising diffusion restoration models," Adv. Neural Inf. Process. Syst., vol. 35, pp. 23593–23606, 2022.

[6] Dr. U. Palani, D. Vasanthi, and S. Rabiya Begam, "Enhancement of Medical Image Fusion Using Image Processing," J. Innov. Image Process., vol. 2, no. 4, pp. 165–174, Oct. 2020, doi: 10.36548/jiip.2020.4.001.

[7] Y. Yang, Z. Su, and L. Sun, "Medical image enhancement algorithm based on wavelet transform," Electron. Lett., vol. 46, no. 2, p. 120, 2010, doi: 10.1049/el.2010.2063.

[8] A. Rayan et al., "Utilizing CNN-LSTM techniques for the enhancement of medical systems," Alex. Eng. J., vol. 72, pp. 323–338, Jun. 2023, doi: 10.1016/j.aej.2023.04.009.

[9] L. Rundo et al., "MedGA: A novel evolutionary method for image enhancement in medical imaging systems," Expert Syst. Appl., vol. 119, pp. 387–399, Apr. 2019, doi: 10.1016/j.eswa.2018.11.013.

[10] J. Jose et al., "An image quality enhancement scheme employing adolescent identity search algorithm in the NSST domain for multimodal medical image fusion," Biomed. Signal Process. Control, vol. 66, p. 102480, Apr. 2021, doi: 10.1016/j.bspc.2021.102480.

[11] H. Avcı and J. Karakaya, "A Novel Medical Image Enhancement Algorithm for Breast Cancer Detection on Mammography Images Using Machine Learning," Diagnostics, vol. 13, no. 3, p. 348, Jan. 2023, doi: 10.3390/diagnostics13030348.

[12] L. Chen, P. Bentley, K. Mori, K. Misawa, M. Fujiwara, and D. Rueckert, "Self-supervised learning for medical image analysis using image context restoration," Med. Image Anal., vol. 58, p. 101539, Dec. 2019, doi: 10.1016/j.media.2019.101539.

[13] X. Chen et al., "Recent advances and clinical applications of deep learning in medical image analysis," Med. Image Anal., vol. 79, p. 102444, Jul. 2022, doi: 10.1016/j.media.2022.102444.

[14] J. Liu, J. Li, K. Zhang, U. A. Bhatti, and Y. Ai, "Zero-Watermarking Algorithm for Medical Images Based on Dual-Tree Complex Wavelet Transform and Discrete Cosine Transform," J. Med. Imaging Health Inform., vol. 9, no. 1, pp. 188–194, Jan. 2019, doi: 10.1166/jmihi.2019.2559.

[15] M. Elhoseny and K. Shankar, "Optimal bilateral filter and Convolutional Neural Network based denoising method of medical image measurements," Measurement, vol. 143, pp. 125–135, Sep. 2019, doi: 10.1016/j.measurement.2019.04.072.

[16] X. Liu et al., "A Novel Robust Reversible Watermarking Scheme for Protecting Authenticity and Integrity of Medical Images," IEEE Access, vol. 7, pp. 76580–76598, 2019, doi: 10.1109/ACCESS.2019.2921894.

[17] J. S. Suri et al., "COVID-19 pathways for brain and heart injury in comorbidity patients: A role of medical imaging and artificial intelligence-based COVID severity classification: A review," Comput. Biol. Med., vol. 124, p. 103960, Sep. 2020, doi: 10.1016/j.compbiomed.2020.103960.

[18] W. Wang, Z. Chen, X. Yuan, and X. Wu, "Adaptive image enhancement method for correcting low-illumination images," Inf. Sci., vol. 496, pp. 25–41, Sep. 2019, doi: 10.1016/j.ins.2019.05.015.

[19] H. Wang, X. Hu, X. Zhao, and Y. Zhang, "Wide Weighted Attention Multi-Scale Network for Accurate MR Image Super-Resolution," IEEE Trans. Circuits Syst. Video Technol., vol. 32, no. 3, pp. 962–975, Mar. 2022, doi: 10.1109/TCSVT.2021.3070489.

[20] J. Li, F. Fang, J. Li, K. Mei, and G. Zhang, "MDCN: Multi-Scale Dense Cross Network for Image Super-Resolution," IEEE Trans. Circuits Syst. Video Technol., vol. 31, no. 7, pp. 2547–2561, Jul. 2021, doi: 10.1109/TCSVT.2020.3027732.

[21] S. Kaji and S. Kida, "Overview of image-to-image translation by use of deep neural networks: denoising, super-resolution, modality conversion, and reconstruction in medical imaging." arXiv, Jun. 10, 2019. Accessed: Jul. 13, 2023. [Online]. Available: http://arxiv.org/abs/1905.08603

[22] H. Li et al., "An Annotation-free Restoration Network for Cataractous Fundus Images," IEEE Trans. Med. Imaging, vol. 41, no. 7, pp. 1699–1710, Jul. 2022, doi: 10.1109/TMI.2022.3147854.

[23] Vijayakumar, "A SECURE STEGANOGRAPHY CREATION ALGORITHM FOR MULTIPLE FILE FORMATS," J. Innov. Image Process., vol. 1, no. 01, pp. 1–10, Oct. 2019, doi: 10.36548/jiip.2019.1.001.

[24] T. He and X. Li, "Image quality recognition technology based on deep learning," J. Vis. Commun. Image Represent., vol. 65, p. 102654, Dec. 2019, doi: 10.1016/j.jvcir.2019.102654.

[25] X. Zhang and W. Dahu, "Application of artificial intelligence algorithms in image processing," J. Vis. Commun. Image Represent., vol. 61, pp. 42–49, May 2019, doi: 10.1016/j.jvcir.2019.03.004.

[26] Ş. Öztürk, R. Ahmad, and N. Akhtar, "Variants of Artificial Bee Colony algorithm and its applications in medical image processing," Appl. Soft Comput., vol. 97, p. 106799, Dec. 2020, doi: 10.1016/j.asoc.2020.106799.

[27] M. A. Ghannadi, M. SaadatSeresht, M. Izadi, and S. Alebooye, "Optimal texture image reconstruction method for improvement of SAR image matching," IET Radar Sonar Navig., vol. 14, no. 8, pp. 1229–1235, Aug. 2020, doi: 10.1049/iet-rsn.2020.0058.

[28] Aastha Gour, "Machine Learning Approaches for Image Denoising and Artifact Removal in Medical Imaging," Int. J. Intell. Syst. Appl. Eng., vol. 11, no. 7, 2023.

[29] L. Gaur, U. Bhatia, N. Z. Jhanjhi, G. Muhammad, and M. Masud, "Medical image-based detection of COVID-19 using Deep Convolution Neural Networks," Multimed. Syst., vol. 29, no. 3, pp. 1729–1738, Jun. 2023, doi: 10.1007/s00530-021-00794-6.

[30] T. Rahman et al., "Exploring the effect of image enhancement techniques on COVID-19 detection using chest X-ray images," Comput. Biol. Med., vol. 132, p. 104319, May 2021, doi: 10.1016/j.compbiomed.2021.104319.

[31] S. Huang, M. Huang, Y. Zhang, J. Chen, and U. Bhatti, "Medical image segmentation using deep learning with feature enhancement," IET Image Process., vol. 14, no. 14, pp. 3324–3332, Dec. 2020, doi: 10.1049/iet-ipr.2019.0772.

[32] Y. Han, L. Huang, Z. Hong, S. Cao, Y. Zhang, and J. Wang, "Deep Supervised Residual Dense Network for Underwater Image Enhancement," Sensors, vol. 21, no. 9, p. 3289, May 2021, doi: 10.3390/s21093289.

[33] Y. Wang, J. Guo, H. Gao, and H. Yue, "UIEC^2-Net: CNN-based Underwater Image Enhancement Using Two Color Space." arXiv, Apr. 13, 2021. Accessed: Jul. 14, 2023. [Online]. Available: http://arxiv.org/abs/2103.07138

[34] Y. Pourasad and F. Cavallaro, "A Novel Image Processing Approach to Enhancement and Compression of X-ray Images," Int. J. Environ. Res. Public. Health, vol. 18, no. 13, p. 6724, Jun. 2021, doi: 10.3390/ijerph18136724.

# Cold Chain Logistics Path Planning and Design Method based on Multi-source Visual Information Fusion Technology

Ke XUE[1], Bing Han[2]

School of Logistics and e-Commerce, Henan University of Animal Husbandry and Economy, Zhengzhou, 450044, China

*Abstract*—**Complete cold chain logistics is needed to control the whole temperature of refrigerated and frozen food, including the closed environment, storage and transportation when loading and unloading goods. Studying how to optimize vehicle scheduling and reduce transportation time and transportation costs is very important. The research object of this paper is the path planning of urban cold chain logistics. This paper will consider the cold chain distribution of multi-vehicle coexistence, build an integer programming model, design a targeted ACO (Ant Colony Optimization) solution model, and verify it with an example. Based on multi-source visual information fusion technology, these independent heterogeneous data sources are accessed through cloud computing resource integration technology to establish a unified data integration middleware. The pheromone update model selected in this paper is the ant week model, which uses global information to record the optimal path of ants. The results show that the satisfaction of delivery time is far behind, and even the average satisfaction of key customers with high value is only 55.1%, which is 18.3% higher than that of the planning without considering value. This method can provide a real-time optimized path in an effective time range and improve the efficiency of distribution services, which has certain theoretical significance and practical value.**

*Keywords—Multi-source visual information fusion; cold chain logistics road; path planning; ant colony optimization*

## I. Introduction

Effective distribution has become the key link of cold chain logistics because agricultural products are greatly affected by natural conditions and easily spoiled. Logistics operations such as low-temperature production, low-temperature transportation and low-temperature storage are selected in the cold chain logistics distribution process, which is a key logistics project supported by the state in recent years [1]. At the present stage of China's development, the logistics platforms of various industries have become perfect, and only cold chain logistics is still in a new developing position. Then the demand for cold chain logistics for the Chinese market is objective, and the overall growth rate of the cold chain logistics market is gradually increasing. However, some fresh agricultural products have caused huge losses in the process of circulation and consumption due to their special quality, and people's requirements for cold chain logistics and transportation are constantly improving. The development of China's cold chain is facing unprecedented challenges.

The role of cold chain logistics in industries such as food, medical, and chemical is increasingly prominent. Ensuring that cold chain items are not damaged during the continuous process from production to consumption in low temperature environments is the core task of cold chain logistics. However, in practical operation, cold chain logistics faces many challenges, such as unreasonable path planning, high energy consumption, and insufficient real-time monitoring. To address these issues, this study applies multi-source visual information fusion technology to cold chain logistics path planning and design, aiming to improve the efficiency and reliability of cold chain logistics. Multi source visual information fusion technology is a method that comprehensively utilizes computer vision, image processing, and pattern recognition technologies to obtain and integrate visual information from multiple sources. In the field of cold chain logistics, multi-source visual information fusion technology can obtain multiple information such as temperature, humidity, and location of goods, and based on this information, path planning and design can be carried out to achieve optimal resource allocation. This model will obtain real-time status information of goods through computer vision and image processing technology, and classify and analyze the information through pattern recognition technology. Then, based on the obtained information, the model will use optimization algorithms for path planning and design, ensuring that the goods reach their destination with the shortest path and lowest energy consumption, while meeting temperature and other conditions.

In the cold chain delivery where multiple vehicles coexist, the contribution points of the integer programming model based on multi-source visual information fusion technology are as follows:

*1) By* integrating multi-source visual information, this model can obtain more comprehensive information on goods and vehicles, thereby better planning distribution routes. This helps to reduce transportation costs, reduce energy consumption, and improve on-time delivery rates and customer satisfaction.

*2) Multi* source visual information fusion technology can monitor the status and location of goods in real time, detect potential problems in a timely manner, and provide early warnings. This helps to reduce cargo losses, ensure food safety, and provide better customer service.

*3) Through* integer programming models, the number of vehicles, loading capacity and route arrangement can be optimized to improve resource utilization efficiency. In addition, different vehicles can collaborate and cooperate to achieve more efficient delivery and improve overall operational efficiency.

Section I of this study elaborates on the background of cold chain logistics to control the closed environment of refrigerated and frozen food, as well as the storage and transportation of goods during loading and unloading. Section II elaborates on the research achievements of scholars who have become a hot topic in cold chain logistics distribution. Section III considers the cold chain distribution of multiple vehicles coexisting, establishes an integer programming model, and designs a targeted ant colony optimization (ACO) solution model. Section IV accesses these independent heterogeneous data sources through cloud computing resource integration technology to establish a unified data integration middleware. The pheromone update model chosen in this article is the Ant Week model, which utilizes global information to record the optimal path of ants. The results show that this method can provide real-time optimization paths within an effective time range. Section V summarizes the entire article. The integer programming model based on multi-source visual information fusion technology is an innovative method that can promote technological progress and industrial upgrading in the cold chain logistics industry.

## II. RELATED WORK

In recent years, cold chain logistics and distribution has become a research hotspot, mainly focusing on single vehicle route optimization, such as Bittencourt et al. accurately depict the distribution scene and study the impact of real-time traffic on the cold chain logistics route optimization in the road network [2]; Ouyang comprehensively considered time window, food spoilage, equipment-energy consumption and traffic congestion, and to get the optimal vehicle route distribution scheme, a stochastic vehicle route model with time window was constructed [3]. Amaruchkul put forward a mixed integer linear programming model, which combined the food production chain and quality loss, and analyzed the application value of this model with a case [4]. Established a model based on perishable property and time constraint, which had a significant impact on the cost, and solved it by tabu search algorithm [5]; In view of the problems existing in Yu's cold chain logistics and distribution, some effective suggestions are put forward. While improving the distribution efficiency, we should also ensure the quality and safety of products and optimize the process from the whole [6]; Li et al. deduced the calculation formula of algorithm convergence based on the related theoretical research of multi-objective generalized ACO (Ant Colony Optimization) and verified the correctness of the convergence and time complexity theory of multi-objective generalized ACO according to two given examples [7]. Zhang et al. analyzed the optimization problem of the cold chain logistics distribution path with the process of return and recovery. They provided a reference for the decision-making operation of cold chain transportation and distribution enterprises [8]. Chen took into account the timeliness

requirements of fresh products and, based on customer information feedback, studied and analyzed the feasibility of simultaneous delivery and pick-up processes to prevent the transport vehicles from driving back with no load [9]. Zhang et al. proved that the improved Dijkstra algorithm has better solution efficiency, and the quality of the final solution is improved compared with the traditional algorithm through simulation experiments [10]. Song et al. gave an effective distribution model to solve the distribution problem of cold chain perishable products in economically poor areas [11]. The purpose of the improved vehicle routing problem and optimal allocation is to reduce the pain and hunger in poor areas, not the distance and time.

In order to ensure the safety of food, a complete cold chain logistics is needed to control the whole temperature of refrigerated and frozen food, including the closed environment, storage and transportation when loading and unloading goods. In reality, due to the difference in delivery time and other factors, the delivery time may change, and the research of dynamic vehicle scheduling problems is still in the initial stage. The information on vehicle dynamic scheduling problem optimization is related to the travel time and the running speed of vehicles [12], [13]. Generally speaking, there is a positive correlation between vehicle transportation cost and vehicle mileage. Reasonable planning of vehicle transportation routes and minimizing vehicle mileage are the primary ways to reduce vehicle transportation costs. It is very important to study how to optimize vehicle scheduling, reduce transportation time and transportation cost [14].

Multi source visual information includes various information, such as vehicle position, speed, and cargo status is of great significance for path planning and design. However, in previous studies, this information was not fully utilized, resulting in the model being unable to make optimal decisions based on actual situations. Cold chain logistics has its unique characteristics, such as temperature control, shelf life of goods, etc. These characteristics have a significant impact on path planning and design. In cold chain logistics, the number of vehicles and goods that need to be considered may be very large, so efficient algorithms are needed to solve the problem. Therefore, it is of great practical significance to study vehicle optimal scheduling and route optimization as important contents. This paper will consider the cold chain distribution situation of multi-vehicle coexistence, build an integer programming model based on multi-source visual information fusion technology, design a targeted ACO solution model, and verify it with an example.

## III. RESEARCH METHOD

### A. Logistics VRP Analysis

The process of cold chain logistics includes four aspects: frozen processing, frozen storage, refrigerated transportation and distribution, and frozen sales [15], [16]. Logistics VRP(Vehicle Routes Planning) is generally defined as giving the location, distance, demand and other related information of one (or more) warehouses and multiple customers, seeking appropriate driving routes, so that vehicles can complete the delivery or pick-up work through them in an orderly manner, and achieve a certain purpose.

The products distributed in the cold chain logistics are generally fresh products, which are corrosive. Fresh product sellers often make a prior agreement on the delivery time of the products and restrict the distributor from delivering the goods within the agreed period. Therefore, cold chain logistics distributors must consider the change in air temperature when delivering. Cold chain logistics not only requires the minimization of the cost in circulation but also has certain requirements for time, and its response to the market should be sensitive.

VRP problem is the most studied VRP problem at present. Firstly, the basic elements of the transportation problem, the corresponding constraints, the total cost value target that the logistics enterprise hopes to achieve, etc., are defined. The artificial intelligence algorithm approaches the optimal solution step by step and has strong applicability in dealing with large-scale and multi-node transportation path problems [17]. The new hybrid algorithm and structure greatly improve the efficiency of problem-solving and enrich the feasibility of theoretical results and practical applications. In the context of the close combination of traditional algorithms, it is also helpful to discover the advantages, disadvantages and application scope of traditional nature-imitating algorithms. The inspiration for particle swarm optimization comes from this method.

The VRP problem is based on the TSP (Traveling Salesman Problem) problem, which assumes that the distance between customers is known and the quantity of goods delivered by vehicles to customers is the same. Then, the route is reasonably planned to make the total distribution route the shortest. The specific situation is shown in Fig. 1:
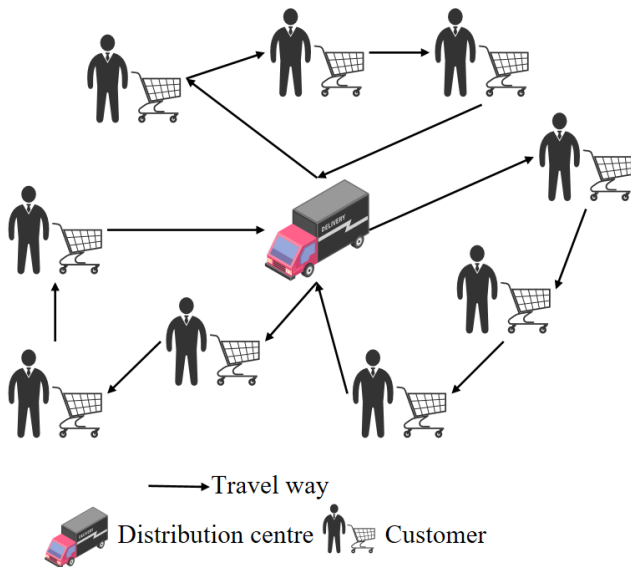


Fig. 1. Schematic diagram of vehicle scheduling problem.

It is the most basic carrier of cargo transportation and information transmission, and its main attributes include the maximum cargo load, the longest driving distance, whether it can be returned halfway, etc. The longest transportation distance of vehicles directly determines the coverage and size of the transportation network. With the distribution center as

the dot, the radius of serviceable demand points and the longest distance between various demand points directly affect the number of serviceable demand points [18], [19]. Different types of distribution centers have different supporting facilities, different service targets and different service scopes, which can be aimed at a certain type of customer or a variety of customers. In violation of the time constraint, the customer has a certain probability of refusing to deliver the transport vehicle.

The vehicle routing optimization problem is based on the travelling salesperson problem with some restrictions, including limiting the quantity of product demand, delivery time, loading quantity of vehicles, driving distance of vehicles, etc. When multiple customer numbering schemes are selected to solve the problem, a satisfactory solution with higher quality can usually be obtained, but the amount of calculation will be doubled.

*B. Multi-source Data Information Analysis of Cold Chain Logistics VRP*

Logistics informatization refers to a series of processing such as collecting, classifying, querying, tracking and summarizing the information generated in the logistics distribution process by using Internet technology and modern information technology in the logistics supply chain, with the development of e-commerce and virtual business in modern enterprises. Cold chain logistics distribution center refers to the intermediate storage base set up to promote the rapid circulation of fresh products from the place of production to the place of sale. Enterprises or individuals hope to visit the optimized best-driving route in cold chain logistics distribution anytime and anywhere. At the same time, they also hope that the platform for optimizing the route can be dynamically upgraded.

There is a maximum cargo capacity of the vehicle, and there may be a time limit for delivery. It is necessary to arrange the picking-up time reasonably, organize the appropriate driving route so that the user's needs can be met, and at the same time, a certain cost function can be minimized, such as the minimum total working time, the shortest route and the minimum cost [20].

The ant colony system represents the feasible solution by the ant colony's advancing route, and each route of the ant colony's advancing route constitutes the solution space. The pheromones released by ants with shorter routes are more and move continuously. Under the action of positive feedback, the ant colony will take the optimal route, and the solution at this time is the optimal solution.

When the ant colony is moving, the pheromone is constantly evaporating, assuming that the parameter $\rho(0 < \rho < 1)$ represents the rate of pheromone volatilization, that is:

$$\begin{cases} \tau_{ij}(t+1) = (1-p)\tau_{ij}(t) + \Delta\tau_{ij} \\ \Delta\tau_{ij} = \sum_{k=1}^{n}\Delta\tau_{ij}^{k} \end{cases} p \in (0,1) \qquad (1)$$

In the formula, $\Delta\tau_{ij}^{k}$ represents the pheromone concentration released by the $k$th ant between the route of town $i$ and town $j$; $\Delta\tau_{ij}$ represents the sum of pheromone

concentrations released by all ants between the route of Town $i$ and town $j$.

The determination of the distribution type of random variables is often the assumption of the distribution type after preprocessing the collected data. The theoretical distribution of many random variables in the system can be directly determined by experience. A triangle is a continuous probability distribution with the lower limit of $a$, the mode of $b$ and the upper limit of $c$.

$$f(x|a,b,c) = \begin{cases} \frac{2(x-a)}{(b-a)(c-a)}, & a \leq x \leq b \\ \frac{2(b-x)}{(b-a)(b-c)}, & b \leq x \leq c \\ 0, & other \end{cases} \quad (2)$$

The mathematical expected value of the random variable $x$ is:

$$E(X) = \frac{a+b+c}{3} \quad (3)$$

When using GPS data of floating cars to calculate road weight, the influence of invalid data points must be considered. Then, an average speed estimation model based on travel time is selected to calculate the average speed of each road section. At the same time, road quality and energy consumption loss are considered. Finally, the estimation method of road weight is obtained by combining these kinds of information. The estimation formula for the road weight of a single section is:

$$w(i) = \alpha \frac{L_i}{V_i} \beta Level_i \quad (4)$$

Where $w(i)$ is the road weight of the road section $i$, $L_i$ is the distance travelled by the floating car in the road section $i$, $V_i$ is the average speed of the road section $i$, and $Level_i$ is the evaluation function of the comprehensive quality of the road section; $\alpha, \beta$ is the correlation coefficient.

New information will constantly appear, which will affect the driving path of vehicles to varying degrees. The quality of refrigerated products changes with the passage of time, weather and seasons, the traffic conditions during rush hour and the penalty cost when the distribution violates the time window. The traffic volume of different sections in a day also changes with time.

At present, the development direction of information processing mainly includes integration and fusion. Among them, the former is the basic premise and material basis of an information fusion system. Therefore, the realization of a multi-source visual information fusion service in the process of logistics distribution can effectively solve objective problems such as collaborative scheduling between the logistics center and logistics distribution, optimization of the logistics distribution path, logistics tracking and value-added information service under uncertain conditions.

The multi-source data information of the cold chain vehicle route optimization model is provided by different application resources of the cloud computing center, and the data formats of these different resources are quite different. These independent heterogeneous data sources are accessed through cloud computing resource integration technology to establish a unified data integration middleware as shown in Fig. 2.

The terminal acquisition layer is the data resources on which this information system relies, including the RFID system (to obtain goods information) and the GPS system (to obtain real-time in-transit position information of vehicles) under the unified management of the database management and control system.
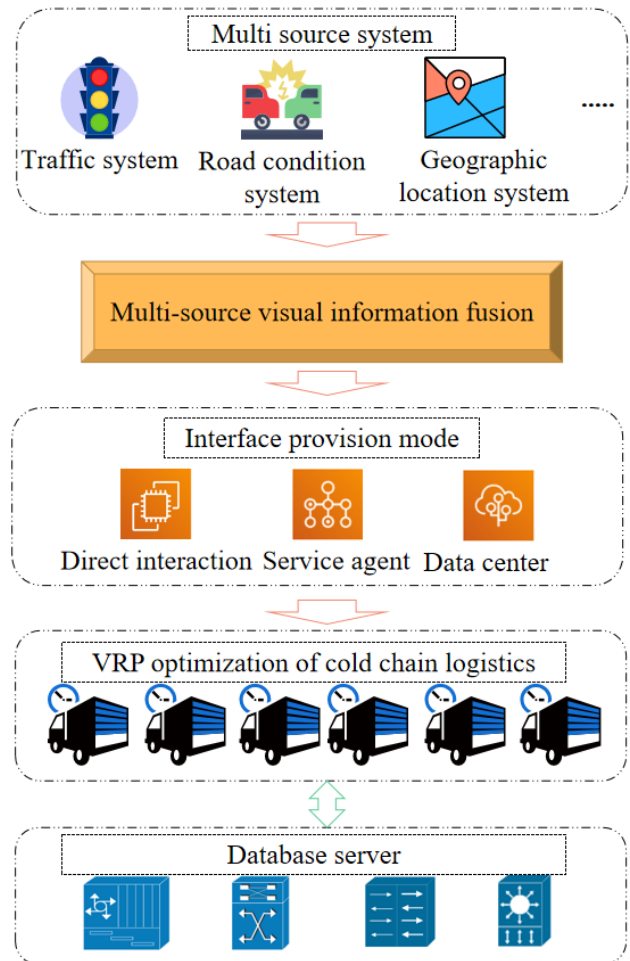


Fig. 2. Vehicle dynamic optimization model based on multi-source visual information fusion technology.

On the one hand, the system can plan the best route with time as a consideration; On the other hand, by sending different recommended routes to vehicles, the traffic efficiency is maximized, and the fuel loss caused by frequent braking and starting of vehicles is reduced, the waste of transportation resources is effectively reduced, and the environment is protected at the same time. These multi-source data can provide real-time data and make the calculated optimal path closer to the actual distribution service.

### C. Vehicle Trajectory Analysis and Matching

The research object of this paper is the path planning of urban cold chain logistics, and its model is based on one or more logistics centers meeting multiple customer points in the region. In practice, the running unit is a truck with refrigeration

equipment to transport fresh products. Make the objective function closer to reality according to the actual situation, and get further optimization.

A penalty function is introduced if refrigerated trucks deliver goods to customers over time. If it is delivered in advance, a reward function is introduced. Generally speaking, refrigerated vehicles' cost includes fixed and variable costs. In this paper, the former refers specifically to the precipitation cost of allowing each distribution vehicle to run normally, which is basically linearly proportional to the total time travelled by the vehicle, generally including wages, maintenance, fuel costs, etc., and is a known constant.

Which increases with the increase in transportation distance, and the two are in direct proportion.

Department:

$$C_1 = \sum_{i \in N} \sum_{j \in N} \sum_{k \in K} tcost_k * x_{ijk} * d_{ij} \qquad (5)$$

$tcost_k$ represents the unit transportation cost of transport vehicle $k$, $d_{ij}$ represents the distance from customer $i$ to customer $j$, $tcost_k$, $d_{ij}$ is known, $x_{ijk}$ is a variable of 0-1, which represents the process of vehicle $k$ from point $i$ to point $j$, if there is this process, it is 1; otherwise it is 0.

Set the upper and lower limits of the customer's patience time, and establish the correlation function between time and compensation within this time limit. Once the customer exceeds the lower limit of his time limit, the penalty will be calculated automatically. The Equation (6) is the general calculation formula of penalty cost:

$$K(t)_{ij} = \begin{pmatrix} 0, & t_{ik} < a \\ M(j)(t_{ik} - a), & t_{ik} > a \end{pmatrix} \qquad (6)$$

Where, $K(t)_{ij}$ represents the time window penalty cost of the $i$th car serving customer $j$; $M(j)$ represents the penalty cost to be paid per unit time after exceeding customer $j$ time tolerance. $t_{ik}$ indicates the time when the $k$th car arrives at customer $i$.

In cold chain logistics, the main factors that cause goods damage are time, including transportation time and unloading time, and the cost of goods damage at node $i$ is transportation loss cost plus unloading loss cost. Therefore, the total cost of goods damage can be expressed as:

$$Z = \sum_{i=1}^{N} C_{goods} \times q_i \times (\rho_1 D_{0 \to i} + \rho_2 D_{off_i}) \qquad (7)$$

$\rho, \rho_2$ is the loss ratio of transportation and unloading, and $D_{0 \to i}$, $D_{off_i}$ is the time spent on transportation and unloading.

Customers' demand is often affected by factors such as the brand, quality, marketing methods, personal preferences, different seasons, after-sales and so on of dairy products, resulting in uncertain changes. In this paper, the demand for urban dairy cold chain logistics distribution is regarded as a random variable, and the premise of its optimization is to obey the normal distribution of customer demand. When the customer demand is higher than the actual vehicle load, the order will be cancelled, and at the same time, customer satisfaction will be reduced, resulting in out-of-stock costs. The specific formula is as follows:

$$C = \tau \sum_{k=1}^{m} max\{d_k - s_k\} \qquad (8)$$

Where, $\tau$ is the shortage cost per unit cold chain product; $d_k$ the actual total demand of the retailers served by the $k$-car; $s_k$ is the actual load capacity of the vehicle $k$.

Time is very important for customers, and customers hope that goods can be delivered on time within the agreed time. In this paper, it is assumed that the service attitude satisfaction of the delivery staff is 1, and the customer's satisfaction with the delivery time is calculated according to the customer's requirements for the delivery time window.

In this paper, it is assumed that customer satisfaction is linearly related to time, when the vehicle arrives in the best time window agreed by the customer, $e_j \leq t_j \leq l_j$, and when the vehicle arrives at the customer point outside the best time window of the customer point $E_j \leq t_j \leq e_j, l_j \leq t_j \leq L_j$. The delivery time satisfaction expression can be expressed as:

$$U(S_j) = \begin{cases} \left(\frac{t_j - E_j}{e_j - E_j}\right)^\alpha, & E_j \leq t_j < e_j \\ 100\%, & e_j \leq t_j < l_j \\ \left(\frac{L_j - t_j}{L_j - l_j}\right)^\alpha, & l_j \leq t_j < L_j \end{cases} \qquad (9)$$

Where $[e_j, l_j]$ is the customer's expected time window, $[E_j, L_j]$ is the customer's acceptable time window, and $\alpha$ is the customer's sensitivity coefficient to time.

The methods for solving objective programming problems can be divided into exact and heuristic algorithms. It is an important idea of a modern, improved heuristic algorithm to search the neighborhood of the current solution many times according to a fixed search strategy. It constantly feeds back the results of the solution to improve the process of the initial solution continuously.

The remaining pheromones on the road section will gradually weaken with the continuous accumulation of time. Every time each ant visits all the cities, the number of pheromones on the road section will change accordingly. The following formula can describe the change and adjustment of pheromones on the path, namely:

$$\tau_{ij} = (t + 1) = (1 - \rho)\tau_{ij}(t) + \Delta\tau_{ij} \qquad (10)$$

$\rho$ is the attenuation coefficient of pheromone, and $\Delta\tau_{ij}$ is the amount of pheromone released by ants from node $i$ to node $j$.

In this paper, the mathematical model of dairy products' logistics and transportation problems is established, and the best path selection scheme is obtained by solving the problem model with related algorithms. ACO has the advantages of fewer iterations, a relatively stable solution process and relatively high solution quality in this paper.

Generally speaking, many models can calculate the pheromone concentration. This paper takes the ant week model as the basic model.

$$\Delta\tau_{ij}^k = \begin{cases} \frac{Q}{L_k}, & \text{If the kth ant passes through } sec\,tion\,(i,j) \text{ in this cycle} \\ 0, & other \end{cases}$$

$$(11)$$

ACO is inspired by the behavior of ants seeking the shortest path to get food in the foraging process. The simple behavior rules of ants make the whole ant colony present intelligent behavior, which makes it diverse and positive. In the process of foraging, diversity can prevent ants from entering a dead end and falling into an infinite cycle.

It has a unique positive feedback mechanism of iteration results and parallel calculation method, strong compatibility between algorithms, stable iteration results, etc. The specific implementation process of the improved ACO is shown in Fig. 3.
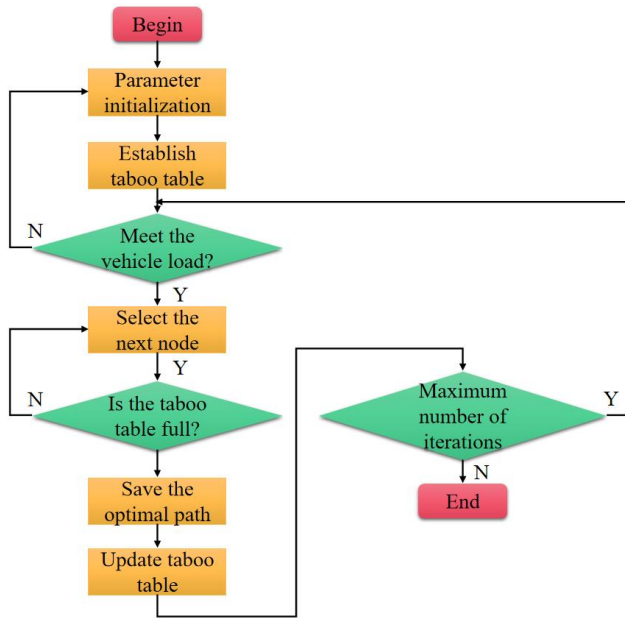


Fig. 3. Improve the calculation process of post-ACO.

Therefore, in order to make it more likely that customers with shorter waiting times will be selected as the next transportation point when selecting the next customer point, the waiting factor is added to the rules for selecting the next node.

$$w_{ijk} = \frac{1}{rt_j - t_{ik}} \tag{12}$$

$t_{ik}$ is the moment when the $k$ -th car arrives at point $i$.

The pheromone update model selected in this paper is the ant week model. Using the global information, the pheromone increment is only related to the overall search route and has nothing to do with the specific route. After all the ants have gone through one traversal, the best route for recording the ants is $L\_best$, and the pheromone matrix is updated:

$$Tau = Rho * Tau + \Delta Tau \tag{13}$$

$$\Delta Tau = \Delta Tau + \frac{Q}{L\_best} \tag{14}$$

$Rho$ represents the pheromone residual coefficient, $\Delta Tau(i,j)$ represents the pheromone increment of all ants on

the route from the $i$th city to the $j$th city, and $Q$ represents the pheromone increase intensity coefficient.

The core idea of vehicle trajectory analysis and matching is to fully consider and analyze the relationship between the front positioning point. When the GPS positioning point of the floating car is far away from the road intersection, it is a common situation to determine the optimal road section that matches it through the weight calculation model, which is the most common in map matching.

Assuming that the two endpoints of the road section are $P_1(x_1, y_1), P_2(x_2, y_2)$ and the position coordinates of the current GPS positioning point are $P_0(x_0, y_0)$, the distance between the positioning point and the road section to be matched can be directly obtained by using the distance formula from point to line, which is marked as $dis$. Then the function of calculating the distance weight through this distance is as follows:

$$w_{dis} = h_1 * f(dis) \tag{15}$$

Where $h_1$ is the distance weight coefficient, and $f(dis)$ is the quantization function of the distance weight.

In this paper, the objective function is a combination of the lowest cost and the largest repurchase degree, so the objective function is directly defined as the fitness function. The fitness function is defined as:

$$f_i = z_i = \sqrt[2]{d_1 d_2} \tag{16}$$

$f_i$ represents the fitness of the $i$th chromosome and $z_i$ is its corresponding function value.

## IV. RESULT ANALYSIS

On the basis of the optimization mentioned above analysis, model construction and algorithm research and analysis of urban dairy products logistics distribution under uncertain demand, this paper selects F enterprise as an example to analyze its demand for dairy products distribution optimization, understand its distribution reality, and introduce MATLAB software to program ACO, then make a solution, and finally verify the scientificity of the algorithm and the effectiveness of the model.

Take a certain distribution service as an example. The F Enterprise Distribution Center provides distribution services for its 15 stores, and the distribution center has 8 refrigerated trucks. The more ants there are, the more accurate the optimal solution will be. As the algorithm converges closer to the optimal solution, the positive feedback of information decreases, resulting in a large number of repeated solutions, which consumes resources and increases the time complexity.

In this paper, the number of ants is set to 50. Before the service, the potential value of each customer is mainly determined by the breadth and depth of their social circle. Therefore, when classifying customers, the potential value of customers is determined by the product of the coverage of the customer's social circle and the importance of the customer in the social circle.

First of all, we set the geographic location information. For the convenience of calculation, we set the origin of the plane's geographic coordinates as the logistics center itself. Please see Table I below.

The dynamic data taken in the simulation refers to the road conditions, traffic congestion and vehicle speed. These changes in dynamic data may cause changes in the delivery time and cost of refrigerated vehicles, and the dynamic data of each journey can be obtained periodically. Fig. 4 shows the speed of the vehicle in a certain period of time.

TABLE I.    GEOGRAPHICAL LOCATION INFORMATION OF A LOGISTICS COMPANY AND ITS CUSTOMERS

| Customer name | Geographic information |
|---|---|
| Logistics centre | (0,0) |
| A customer | (30.1,2.1) |
| B customer | (22.6,-2.2) |
| C customer | (35,0) |
| D customer | (24.1,5.5) |
| E customer | (29.8,2.3) |
| F customer | (31.5,1.8) |
| G customer | (33.6,1.5) |
| H customer | (30.8,2.7) |
| I customer | (29.5,2.2) |
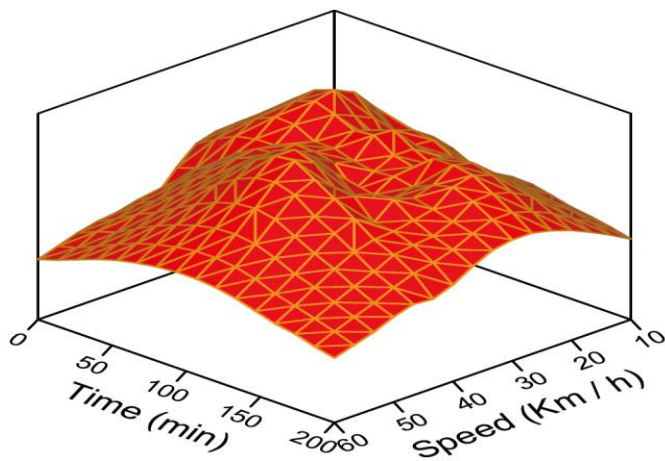


Fig. 4.    Vehicle speed map.

TABLE II.    TIME WINDOW ARRANGEMENT AND SERVICE TIME OF EACH CUSTOMER

| Distributor number | Time window | Service time |
|---|---|---|
| 0 | 6:00-12:00 | 0 |
| 1 | 7:00-10:00 | 22 |
| 2 | 7:00-10:00 | 29 |
| 3 | 7:00-90:30 | 30 |
| 4 | 7:10-8:00 | 13 |
| 5 | 8:00-10:00 | 24 |
| 6 | 7:00-8:30 | 16 |
| 7 | 7:00-8:00 | 28 |
| 8 | 7:00-9:00 | 11 |
| 9 | 7:00-11:00 | 23 |
| 10 | 7:00-8:50 | 35 |

The goods are distributed as daily necessities for citizens, such as fresh shrimp, ice cream, fresh milk and other perishable products. And ensure that it will not smell bad within 12 hours. The maximum loading capacity of each incubator is about 80 kg, i.e., 0.0 8 tons. In the case of freezing, three cold accumulators are needed, and in the case of refrigerating, two cold accumulators are needed. The holding time is 12 hours. For the distribution of products at room temperature, there is no need to use an incubator. The time window arrangement and service time of each customer are shown in Table II.

The logistics center operation system is a queuing system, and the random arrival of orders accords with the characteristics of the exponential distribution. See Table III for the occurrence times of order arrival time intervals obtained through actual observation.

TABLE III.    NUMBER OF NUMERICAL OCCURRENCES OF ORDER ARRIVAL TIME INTERVAL

| Arrival time interval (min) | Frequency of occurrence | Arrival time interval(min) | Frequency of occurrence |
|---|---|---|---|
| 1 | 7 | 11 | 1 |
| 2 | 2 | 12 | 3 |
| 3 | 4 | 13 | 3 |
| 4 | 5 | 14 | 2 |
| 5 | 5 | 15 | 1 |
| 6 | 4 | 16 | 3 |
| 7 | 10 | 17 | 1 |
| 8 | 4 | 18 | 1 |
| 9 | 3 | 19 | 2 |
| 10 | 6 | 20 | 3 |

After the histogram is used to determine the theoretical distribution of sample data, it is necessary to judge how close the observed sample distribution is to the estimated theoretical distribution, that is, to determine the fitting degree of the estimated theoretical distribution. Fig. 5 shows the comparison between the histogram and probability density curve.
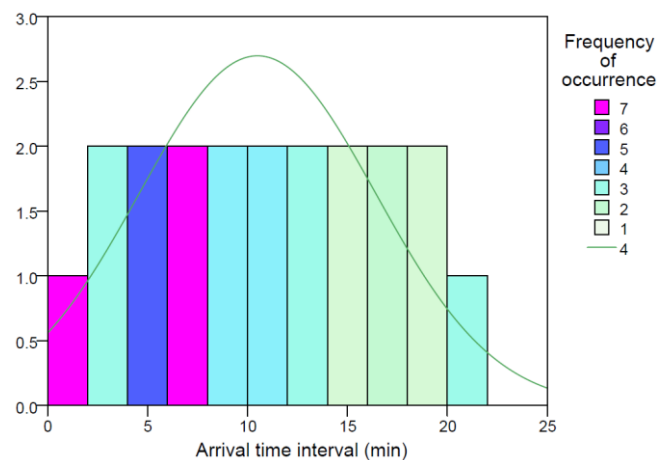


Fig. 5.    Compare with histogram and probability density curve.

It can be seen from the Fig. 5 that the estimated exponential distribution is in good agreement with the observed samples, so

the exponential distribution function can be used to set the parameters of the model and simulate the real system.

According to the basic ACO principle and algorithm flow, this model is solved by MATLAB programming. The best results in 10 experiments are shown in Fig. 6 and 7 below.
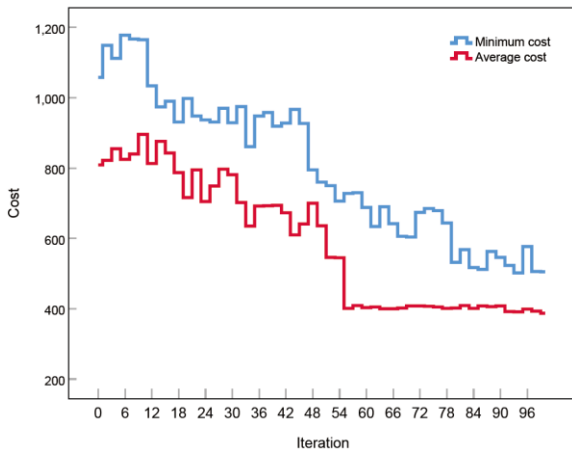


Fig. 6.    Basic ACO iterative process.
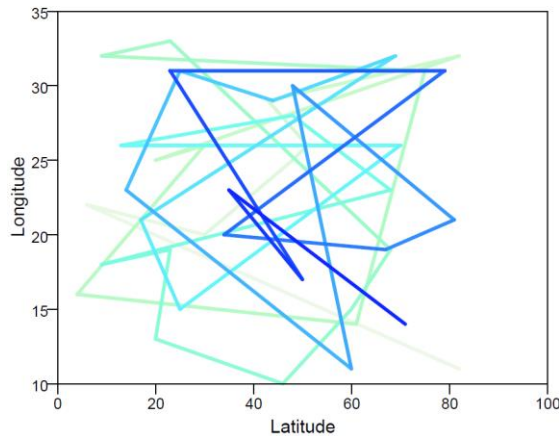


Fig. 7.    Basic ACO optimal path.

At the beginning of the algorithm iteration, with the increase in iteration times, the quality of the current optimal solution rises sharply. The total cost of the current optimal solution changes relatively little after the $20^{th}$ iteration until the total cost of the current optimal solution stops decreasing at the $55^{th}$ iteration, and the global optimal solution is obtained.

Taking the processed target benefit function as the final goal, after running in MATLAB, the display results are shown in Fig. 8.

Compared with VRP, which does not consider customer value, VRP, which does not consider customer value lags far behind in customer satisfaction with delivery time. Even the average satisfaction of key customers with high value is only 55.1%, which is 18.3% higher than that of the planning that does not consider value. The improvement in resource allocation efficiency is obvious.
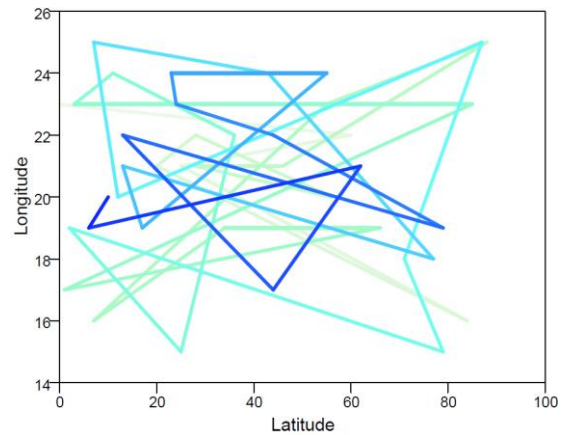


Fig. 8.    Vehicle distribution route considering customer value.

It can be seen that the time and expense of the calculated results are different according to the degree of attention to vehicle delivery cost and delivery time. The evolutionary algebra of the improved ACO model solution and the classical ACO solution in the cloud computing environment are shown in Fig. 9.
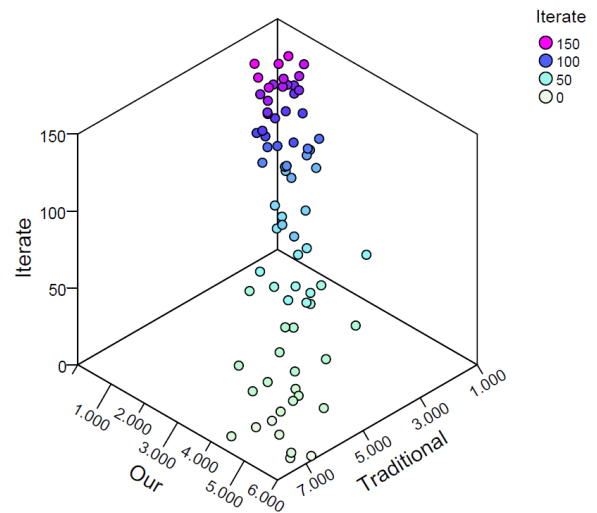


Fig. 9.    Comparison between improved ACO and classic ACO.

When different processors are used, the execution time of the algorithm is different. To a certain extent, the more processors, the shorter the calculation time. It is proved that the shortest path calculation is correct, which can effectively solve the path planning problem on the road network with traffic rules.

In practical applications, we can evaluate the performance of models by comparing the performance of different algorithms. However, for cold chain logistics, due to issues related to food quality, safety, and other aspects, we still need to consider some additional factors. For example, different foods have different temperature requirements, and some foods need to be stored or transported at specific temperatures, otherwise it may affect their quality or safety. Therefore, when establishing integer programming models and designing targeted ant colony optimization (ACO) solving models, we

need to fully consider these factors to ensure that the model can meet practical needs.

In addition, we should also note that the ant colony optimization algorithm itself has some limitations. For example, during the ant search process, they may fall into local optima and cannot find global optima. Therefore, when designing targeted ant colony optimization (ACO) solving models, we need to take some measures to avoid this situation. For example, suitable heuristic information can be set to guide ants in their search direction, or random factors can be introduced to jump out of the local optimal solution.

## V. CONCLUSION

Logistics operations such as low-temperature production, low-temperature transportation and low-temperature storage are selected in the cold chain logistics distribution process, which is a key logistics project supported by the state in recent years. In reality, the delivery time may change due to the difference in delivery time and other factors, and the research on dynamic vehicle scheduling problems is still in the initial stage. The information on vehicle dynamic scheduling problem optimization is related to the travel time and speed of vehicles. This paper will consider the cold chain distribution situation of multi-vehicle coexistence, build an integer programming model based on multi-source visual information fusion technology, design a targeted ACO solution model, and verify it with an example. The results show that the satisfaction of delivery time is far behind, and even the average satisfaction of key customers with high value is only 55.1%, which is 18.3% higher than that of planning without considering value. The improvement in resource allocation efficiency is obvious. And it shows the correctness in calculating the shortest path, which can effectively solve the problem of cold chain logistics path planning with traffic rules constraints.

However, this study still has certain limitations. The acquisition and processing of multi-source visual information requires a large amount of manpower and technical support. Planning models may involve complex algorithms and data processing processes, resulting in reduced interpretability of the model. This may affect the user's trust and acceptance of the model results. In the future, while ensuring model performance, try to simplify the complexity and computational complexity of the model as much as possible. Visualization techniques and interpretive algorithms can be used to make the model results more intuitive and understandable. In addition, domain experts can also be invited to evaluate and validate the model, improving its credibility and acceptance.

## COMPETING OF INTERESTS

The authors declare no competing of interests.

## AUTHORSHIP CONTRIBUTION STATEMENT

Ke Xue: Writing-Original draft preparation, Conceptualization, Supervision, Project administration.

Bing Han: Methodology, Software, Validation.

## REFERENCES

[1] X. Meng and X. Li, "Research on optimization of port logistics distribution path planning based on intelligent group classification algorithm," J Coast Res, vol. 115, no. SI, pp. 205–207, 2020.

[2] G. C. de Bittencourt et al., "A solution framework for the integrated problem of cargo assignment, fleet sizing, and delivery planning in offshore logistics," Comput Ind Eng, vol. 161, p. 107653, 2021.

[3] F. Ouyang, "Research on port logistics distribution route planning based on artificial fish swarm algorithm," J Coast Res, vol. 115, no. SI, pp. 78–80, 2020.

[4] K. Amaruchkul, "Planning migrant labor for green sugarcane harvest: A stochastic logistics model with dynamic yield prediction," Comput Ind Eng, vol. 154, p. 107016, 2021.

[5] N. Balakrishnan, Q. Xie, and D. Kundu, "Exact inference for a simple step-stress model from the exponential distribution under time constraint," Ann Inst Stat Math, vol. 61, pp. 251–274, 2009.

[6] X. Yu, "On-line ship route planning of cold-chain logistics distribution based on cloud computing," J Coast Res, vol. 93, no. SI, pp. 1132–1137, 2019.

[7] Y. Li, M. K. Lim, and M.-L. Tseng, "A green vehicle routing model based on modified particle swarm optimization for cold chain logistics," Industrial Management & Data Systems, vol. 119, no. 3, pp. 473–494, 2019.

[8] L.-Y. Zhang, M.-L. Tseng, C.-H. Wang, C. Xiao, and T. Fei, "Low-carbon cold chain logistics using ribonucleic acid-ant colony optimization algorithm," J Clean Prod, vol. 233, pp. 169–180, 2019.

[9] Y. Chen, "Location and path optimization of green cold chain logistics based on improved genetic algorithm from the perspective of low carbon and environmental protection," Fresenius Environ Bull, vol. 30, no. 6, pp. 5961–5973, 2021.

[10] S. Zhang, N. Chen, N. She, and K. Li, "Location optimization of a competitive distribution center for urban cold chain logistics in terms of low-carbon emissions," Comput Ind Eng, vol. 154, p. 107120, 2021.

[11] M. Song, J. Li, Y. Han, Y. Han, L. Liu, and Q. Sun, "Metaheuristics for solving the vehicle routing problem with the time windows and energy consumption in cold chain logistics," Appl Soft Comput, vol. 95, p. 106561, 2020.

[12] Y. Lu, X. Xu, C. Yin, and Y. Zhang, "Network optimization of railway cold chain logistics based on freight subsidy," Transp Res Rec, vol. 2675, no. 10, pp. 590–603, 2021.

[13] L. Fu, Q. Liu, and P. Calamai, "Real-time optimization model for dynamic scheduling of transit operations," Transp Res Rec, vol. 1857, no. 1, pp. 48–55, 2003.

[14] L. Li, Y. Yang, and G. Qin, "Optimization of integrated inventory routing problem for cold chain logistics considering carbon footprint and carbon regulations," Sustainability, vol. 11, no. 17, p. 4628, 2019.

[15] B. He and L. Yin, "Prediction modelling of cold chain logistics demand based on data mining algorithm," Math Probl Eng, vol. 2021, pp. 1–9, 2021.

[16] L. Chen, M. Ma, and L. Sun, "Heuristic swarm intelligent optimization algorithm for path planning of agricultural product logistics distribution," Journal of intelligent & fuzzy systems, vol. 37, no. 4, pp. 4697–4703, 2019.

[17] J. Xie, S. Xiao, Y.-C. Liang, L. Wang, and J. Fang, "A throughput-aware joint vehicle route and access network selection approach based on SMDP," China Communications, vol. 17, no. 5, pp. 243–265, 2020.

[18] Y. Jiang, Q. Wu, G. Zhang, S. Zhu, and W. Xing, "A diversified group teaching optimization algorithm with segment-based fitness strategy for unmanned aerial vehicle route planning," Expert Syst Appl, vol. 185, p. 115690, 2021.

[19] X. Liu, J. Ma, D. Chen, and L.-Y. Zhang, "Real-time unmanned aerial vehicle cruise route optimization for road segment surveillance using decomposition algorithm," Robotica, vol. 39, no. 6, pp. 1007–1022, 2021.

[20] H. Liu, C. Miao, and G. G. Zhu, "Economic adaptive cruise control for a power split hybrid electric vehicle," IEEE Transactions on Intelligent Transportation Systems, vol. 21, no. 10, pp. 4161–4170, 2019.

# CDCA: Transparent Cache Architecture to Improve Content Delivery by Internet Service Providers

Alwi M Bamhdi

Umm Al-Qura University, College of Computing, Al-Qunfudah, KSA

*Abstract*—The popularity of on-demand multimedia such as video streaming services has been rapidly increasing the overall Internet traffic volume in the world. As of the beginning of 2023, almost 82% of this global Internet traffic came from video transmission through on-demand online services, trending towards changing the Internet paradigm from location-based to content-based, culminating in a new paradigm of Information-Centric Networking (ICN). ICN focuses on content distribution based on name rather than location, allowing Internet Service Providers (ISP) to implement local content caching systems for faster delivery and reduced transmission delays and unnoticeable jitter or distortions. ICN can be implemented over a Software-Defined Networking (SDN) infrastructure. SDN enables flexible programming and implementation of forwarding packet rules within a network domain seamlessly. This paper proposes a hybrid architecture that combines ICN and SDN to create a transparent in-network caching system for content distribution over the traditional IP network. The architecture aims to improve the performance of Video-on-Demand (VoD) services for customers while efficiently utilizing network provider resources. A prototype called CDCA was developed and evaluated in a Mininet emulation environment. The results of the evaluation demonstrate that the CDCA hybrid architecture to create a caching system for content distribution enhances VoD service performance and optimizes network resource utilization.

*Keywords*—*Content caching; content delivery network; content search algorithm; information-centric networking; multimedia; network function virtualization; software defined networks*

## I. INTRODUCTION

The integration of the Web, ICN, SDN and NFV, juxtaposed the *archaic* Internet. By combining these technologies, there is the potential to enable seamless placement and retrieval of multimedia content by multiple users. The integration of these technologies allows internet network service providers to leverage local caching mechanisms to deliver content to multiple users simultaneously. This unique CDCA approach of a system represents a novel and innovative way of optimizing content distribution and improving the overall user experience. The specific details and benefits of this novel approach are further elucidated in this paper.

### A. Summary of the CDCA Solution

This paper presents a content delivery-based caching framework architecture system called CDCA that typically resides inside network providers' premises, i.e., Internet Service Providers (ISP), using SDN, which is completely transparent for users, content provider applications and network providers. Transparency is applied to all actors: the user, the content provider and the ISP network, which neither needs to modify any application and network equipment. In essence, the SDN/NFV module within the CDCA architecture permits forwarding data packets to the content cache or to the content source server transparently.

The key features and advantages of the CDCA architecture provide for in-network caching. The architecture is applicable to any application communication protocol that follows the client-server model and identifies content using unique logical names, such as HTTP URLs. The combination of the SDN control plane, Proxy, and Cache components enables the orchestration of a distributed caching framework. CDCA ensures that content is transparently delivered as close to the user as possible without any modifications to communication protocols or user clients.

CDCA is designed with horizontal scalability and high manageability in mind, adopting the principles of the microservice architectural pattern style that structures an application as a collection of services. This design approach provides elevated deployment flexibility and high levels of availability, regardless of the network's operational state. Content management within the architecture is driven by rule-based policies, facilitated by distributed decision-making mechanisms and multiple caches distributed throughout the network. These components interact with the SDN centralized control plane to ensure efficient content delivery. Although this topic is relevant and interesting and outside the scope of this paper, it will be addressed in-depth in future research works.

CDCA is designed to be deployed and supported by the ISP premises on the client side. In CDN architecture, the service must be contracted and paid for by the content provider. And also, if the CDN server is not located within the ISP network, it will be not worth it, since it will have to pay for the high bandwidth requested by multiple users' content downloads.

### B. Rest of the Paper

The CDCA architecture is distinct from a traditional Content Delivery Network (CDN) infrastructure. They are not comparable. The unique aspects and differences of the CDCA solution are elaborated in Section IV.

The rest of the paper is structured as follows. Section II covers the background to the concepts and issues related to the topic of this paper. Section III presents the literature review of related works. Section IV presents the CDCA

architecture and in Section V the evaluation and results from the experiments are presented. Section VI discusses some important open issues and challenges to consider for future research related to the CDCA architecture and its content delivery operations, and finally, Section VII concludes the paper.

## II. BACKGROUND

It is a remarkable transformation of the Internet from its humble beginnings as a point-to-point communication network for users to becoming a ubiquitous and essential infrastructure for global everyday communication. Over its nearly 54-year history, commencing as ARPANET, the Internet has evolved and gained popularity, becoming a highly successful and effective communication system that continues to rapidly advance. With the increasing volume of traffic and the complexity of modern services such as file sharing, VoIP, social networking, e-commerce, online gaming, and multimedia streaming, the inadequacies of the Internet's original design have become apparent. The architecture of the Internet has undergone numerous amendments to accommodate these evolving needs, resulting in a progressively more complex system at each stage of its development. This growing complexity poses challenges in terms of implementation, maintenance, and management of new networking services and applications. The costs associated with these tasks continue to rise as the Internet becomes more sophisticated and intricate. However, innovation in information communication and internetworking philosophies helps to mitigate the phenomenon of ossification [1], whilst acknowledging the challenges posed by the limitations of the original design and recognizing the ongoing efforts to innovate and adapt to meet the demands of modern communication and networking needs.

The evolving nature of Internet applications, particularly the significant growth in video streaming services, including both live broadcasts and on-demand content is increasing exponentially. According to Cisco, it has seen a massive buildup of Internet traffic in the order of 4.8 zettabytes during 2022, which is over three times the 2017 rate, led by a combination of increased use of cloud computing, IoT device traffic, video viewing, and the sheer number of new users coming onboard every day. The video traffic constituted 82% of the total Internet traffic in 2021, a substantial increase from over 70% in 2017, excluding video exchanged through Peer-to-Peer (P2P) file sharing [2]. The forecast indicates that Internet video traffic will grow at a rate of more than 31% per year, while online gaming, which is part of the audio/video mix, is expected to grow at a rate of over 50% plus per year until 2025. Currently, most content distribution platforms handle content requests individually, resulting in a unicast delivery paradigm where each user receives content from a Content Delivery Network (CDN) infrastructure separately [43]. However, this approach overlooks the fact that much of the content requested by users is identical to content requested by others just moments ago. As a result, a substantial amount of redundant content is delivered repeatedly over the same network segment, leading to unnecessary strain on service providers' transmission capacity and bandwidth. This inefficiency becomes more significant as the number of users

and unicast content continues to grow. Consequently, new approaches are needed to improve and optimize the efficiency of content distribution.

The ongoing modifications and improvements to the Internet's architecture to accommodate new applications demand faster infrastructure and versatile middleware. However, the modern web still faces many challenges due to incompatibilities inherited from the original design of the Internet. The shift in user behaviour is highlighted, with Internet users now seeking specific content *("what")* rather than focusing on the location of that content *("where")*. This shift necessitates more than simple unicast communication for modern web applications [44]. As a result, network architectures need to be smarter and more flexible to support the exponential growth resulting from the dynamic nature of multimedia content availability and online delivery. This trend is expected to persist in the foreseeable future. To emphasize the magnitude of this growth, a comparison between the content data produced in 2008 amounted to 500 exabytes compared to the present-day zettabyte scale [3]. This example illustrates the substantial increase in content generation and consumption over the years. The need for smarter and more flexible network architectures to support the dynamic nature of content availability and delivery on the modern web is a must with the significant growth in content data generation and consumption.

In recent years, some proposals tried to change the current end-to-end IP packet networking and web search engines to innovate enhanced content-based network architecture, called Information-Centric Networking (ICN) [4]. ICN is based on the principle that the Internet should prioritize the data needed by users rather than focusing on the physical location from which the data can be retrieved. In contrast, the current Internet architecture is host-based and was initially designed to facilitate communication between a limited number of fixed computers and geographically dispersed users. Although ICN offers significant advantages, implementing it as a replacement for the existing Internet backbone would require a radical and impractical overhaul. Consequently, various research efforts have focused on adapting ICN architectures to operate within the constraints of the legacy Internet infrastructure. One approach involves integrating ICN with Software-Defined Networking (SDN) and the OpenFlow protocol, allowing for the implementation of ICN concepts while leveraging the programmability and flexibility of SDN to make it compatible with the current Internet backbone [5]–[8].

The concept of a *"programmable network"* originated as a result of the SDN principles and architecture. The concept of a programmable network was initially driven by the introduction of OpenFlow, an open protocol that enables the configuration of packet forwarding tables in switches. With OpenFlow, network users can actively modify these tables, providing a level of control over the network's behaviour [9]. By utilizing OpenFlow and similar technologies, a programmable network introduces an abstraction layer for switches, allowing the separation of the data and control planes. In this context, the switch functions as a hardware fabric that primarily focuses on transparently forwarding data.

The policy management for handling data content is then handled by software through the control plane functions and mechanisms. This decoupling of data and control planes enables greater flexibility and programmability in network management and configuration.

Over the last few years, Network Functions Virtualization (NFV) [10] has shown the most promising results in the development of advanced computer networking. NFV offers a new approach to developing network services by utilizing programmable software and virtualization means. It replaces traditional proprietary hardware network elements and appliances that perform various network functions, such as Network Address Translation (NAT), Intrusion Detection and Prevention System (IDPS), caching, and more. With NFV, these network functions are implemented as Virtualized Network Functions (VNFs) using software and deployed within Virtual Machines (VMs). This approach enables more flexible and efficient networking and network service deployment. By utilizing NFV, network services can be customized according to specific business needs, allowing for greater agility in serving the ever-changing demands of service providers and end-users. Additionally, NFV brings significant cost savings by eliminating the reliance on expensive proprietary hardware and enabling more efficient resource utilization.

## III. Literature Review

Ooka et al. propose the OpenFlow-CCN, a system architecture joining Content-Centric Network (CCN) and OpenFlow mechanisms to achieve content end-to-end forwarding [6]. In their proposal, the content names are mapped to hierarchical structure hash values and the long prefix matching. In an OpenFlow network, the content packet is forwarded by a unique IP address based on the content name hash value. The architecture was evaluated on the Trema Controller in an OpenFlow network. Their proposal is quite interesting because it does not impose any modification to either the OpenFlow protocol or CCN. CDCA does not require a CCN infrastructure because it uses a traditional IP network.

Nguyen et al. propose an improvement in CCN caching strategy that uses SDN [7]. They implement a wrapper between CCNx software and OpenFlow switch to decode and hash the content name in CCN messages into parameters that an OpenFlow switch can forward, e.g., IP address or port number. They argue that the large naming space offered by these fields restricts the collision probability between two different contentnames. The evaluation shows that the wrapper does not affect forwarding performance but might have name-space problems. CDCA does not require a CCN infrastructure.

Chandra et al., proposed a caching architecture specifically for HTTP on an SDN infrastructure [11]. They concluded that while the OpenFlow protocol maintains an abstraction of control and forwarding planes, it presents challenges when dealing with ICN because it lacks content abstractions. In response to this limitation, Chandra et al. proposed an architecture that utilizes a unique Proxy and multiple caches distributed across the OpenFlow network. In comparison to the CDCA solution provided in this paper, it employs the concept of deploying a Proxy to determine whether content should be fetched from the Cache or the server and it introduces a distributed Proxy and Cache architecture to enhance scalability and resilience. This means that the CDCA Cache architecture is designed to accommodate scalability and provide better fault tolerance and resilience.

Georgopoulos et al. presented OpenCache, an in-network caching system designed specifically for Video-on-Demand (VoD) applications using OpenFlow technology [12]. OpenCache consists of two main components: the OpenCache Node (OCN) and the OpenCache Controller (OCC). The OCC is responsible for determining which videos should be cached, while the OCN handles the storage necessary for video caching. The experiments conducted on OpenCache have demonstrated positive results in terms of video start-up delay, external link usage, and video quality. However, it is noted that these experiments were conducted with a single video client, which may not fully represent the behaviour and performance of OpenCache in real-world production networks with multiple user accesses.

The CDCA concept and solution offered in this paper of finding the Cache that is nearest to the user overcomes the deficiencies from other comparative approaches in so far as making Cache decisions based on user requests in an *on-demand* fashion, rather than relying solely on operator decisions.

## IV. CDCA: Content Delivery Cache Architecture

The CDCA architecture aligns with the SDN principle of having a centralized control plane, which is responsible for controlling and directing the forwarding of data packets within the network. In this architecture, the centralized control plane is designed to handle cacheable requests that adhere to the client-server model, similar to the distributed content Cache architecture embedded inside the provider datacenter [13], but going one step further by deploying the distributed content Cache system inside the ISP infrastructure closest to the end-user, offering better response time and server load-balancing. By leveraging the capabilities of the centralized control plane, the architecture enables efficient management of cacheable requests. The control plane can make decisions regarding content caching based on various factors, such as user demand, network conditions, or predefined rules. These decisions are then communicated to the versatile device responsible for managing the caching process. Overall, the architecture combines the benefits of SDN's centralized control plane with the ability to handle cacheable requests in a client-server model. This integration allows for effective management and optimization of caching operations within the network.

The CDCA operational framework architecture is shown in Fig. 1. It is based on two fundamental components: the Proxy and the Cache. The SDN Controller identifies a potential content flow, such as an HTTP request to a VoD provider via the destination IP address and TCP port information. Once identified, the content flow is redirected to the Proxy component. Within the Proxy, the traffic of interest (content) is mapped to the content re-director module

responsible for forwarding the content request to an appropriate Cache instance where the content is stored. The Cache instance can be located within the same network or distributed across multiple locations. By redirecting the content request to the Cache instance, the CDCA aims to retrieve the content from the Cache instead of fetching it from the original source, thereby reducing latency and network traffic. This mechanism improves the overall efficiency of content delivery by serving frequently requested content from nearby caches. This approach enables faster and more efficient content delivery by leveraging caching capabilities within the network.

Note that the Proxy searches in the DHT to find if the content is cached, then, forward the requests to the Cache or to the Content Server. Fig. 1 illustrates the Cache-missed example shown on the left side, and the successful Cache hit case shown on the right side.
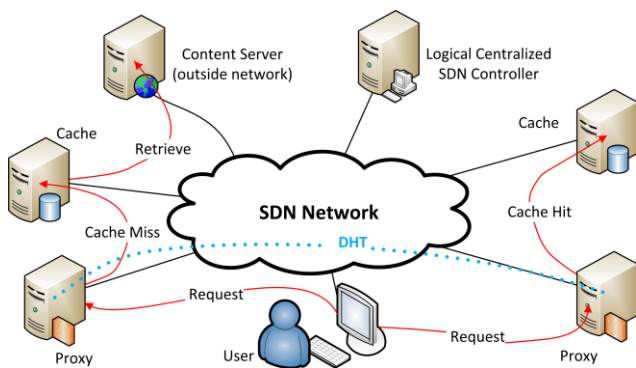


Fig. 1. CDCA system operational framework architecture.

The CDCA architecture implements an on-demand caching scheme for video-on-demand (VoD) services. In this architecture, larger content files can lead to longer transfer delays and higher processing overhead for caching operations, such as storing an entire file in the Cache and delivering it to the user while small files do not need chunking. To overcome this issue, large content files are divided into smaller parts called content chunks. Each chunk is handled independently, allowing for more efficient caching and delivery. This chunk-based delivery approach is specifically designed to handle the delivery of content in smaller segments rather than delivering the entire file at once. All VoD providers analyzed in this work used chunk-based delivery. This indicates that dividing content into smaller chunks is a common practice in the industry, likely due to the advantages it offers in terms of caching, delivery efficiency, and user experience. By adopting this chunk-based delivery approach and caching content chunks on-demand, the CDCA architecture aims to optimize the delivery of VoD content while minimizing transfer delays and processing overhead associated with caching operations.

Chunk-based caching [45] offers several advantages over file-based content caching. By dividing a content file into smaller chunks, it becomes possible to deliver different chunks from multiple caches, improving the efficiency of content delivery. One of the key benefits of chunk-based caching is increased storage efficiency. Instead of storing and replacing entire content files, the caching system can focus on

individual chunks. This fine-grained approach allows for precise caching decisions, reducing the amount of storage required and improving overall Cache utilization. But the distribution of chunks within the network becomes a crucial decision in chunk-based Cache delivery since the placement of chunks across caches can significantly impact the performance and effectiveness of the caching system. Optimizing the distribution of chunks involves considering factors such as Cache proximity to users, network congestion, and popularity of specific content chunks. Efficient chunk distribution strategies typically enhance the caching system's ability to serve content quickly and reduce network traffic. Techniques such as content popularity analysis, adaptive caching algorithms, and dynamic chunk placement are employed to ensure effective distribution and retrieval of content chunks from caches. Furthermore, chunk-based caching has many advantages over file-based content caching. Different chunks of the same content can be delivered from multiple caches. Replacing some chunks instead of a whole content file may increase storage inefficiency. However, careful consideration must be given to the distribution of chunks within the network to optimize performance and achieve efficient content delivery.

In the CDCA architecture, the selection of caches is determined based on either the shortest path to the content or a set of custom rule-based policies. The forwarding decision is made by the Proxy that may receive information from the network management system and server state. Based on this information, the Proxy chooses the best Cache instance. For instance, when a content request is received by the Proxy, it checks if the requested content is already cached in a Cache instance. If a Cache hit occurs, meaning that the content is present in the Cache. This allows for fast and efficient content delivery without the need to retrieve the content from an external source. However, if the requested content is not present in any Cache, resulting in a missed Cache, the Proxy will then forward the request to the nearest Cache. The closest Cache is determined based on factors such as network proximity or predefined routing policies. This Cache, in turn, will request the content from the external Content Server, retrieve and Cache the content locally, and finally serve the user's request. This mechanism ensures that frequently requested content is cached closer to the users, reducing the need for content retrieval from remote servers and improving the overall response time and user experience. By leveraging caching and intelligent Cache selection, the architecture minimizes the latency associated with content delivery, optimizing the use of network resources and enhancing the efficiency of the system. In summary, the Proxy in the CDCA architecture determines Cache hits and misses for content requests. Cache hits allow for direct content delivery, while Cache misses triggering the retrieval of content from the closest Cache or the external Content Server, enabling efficient content caching and delivery to users.

In the CDCA architectural operating scheme, it is possible for multiple instances of the Proxy to be deployed across the network infrastructure "world", where each instance is responsible for coordinating a "Cache island", a group of Cache servers under same management domain. This

distributed deployment allows for efficient content delivery and load balancing. The SDN Controller plays a crucial role in the architecture by receiving network state information from the network management system. Based on this information, the SDN Controller makes forward decisions, determining the best Proxy instance to handle a content request. The goal is to minimize congestion, optimize transfer times, and enhance throughput by selecting the closest Proxy to the requesting user. Each Proxy instance is part of a Distributed Hash Table (DHT) in the overlay network. The DHT network facilitates the storage and retrieval of content-Cache instance mappings throughout the entire network. This distributed approach ensures that the mapping information is accessible and maintained across the network, enabling efficient Cache selection and content delivery. The Cache component, associated with each Proxy instance, is responsible for storing and serving cacheable objects triggered by any user's request within the network. When a cacheable object is requested, the Cache component determines if the object is already stored in the Cache. If it is present, the content is served directly from the Cache, minimizing latency. If the object is not in the Cache, the Cache component retrieves it from the appropriate source (e.g., external Content Server) and stores it in the Cache for future requests. By deploying this strategy of multiple Proxy instances, leveraging SDN-based forward decision-making, and utilizing a DHT overlay network, the CDCA architecture optimizes content delivery, reduces network congestion, and enhances the overall performance of the system.

The CDCA architecture was designed to accentuate high level of scalability and manageability at runtime to accommodate the dynamic nature of network environments. To achieve this, a logically centralized platform, such as a distributed SDN Controller system, is employed to provide scalability and resilience at the SDN layer [14]. While the specific analysis of the distributed SDN Controller system is not within the scope of the paper, it serves as a foundational component for the overall architecture.

Multiple instances of the Proxy and Cache components can be dynamically added or removed at runtime, facilitated by a cloud orchestration platform like OpenStack. This allows for an elastic and flexible solution where the system can adapt to changing demands and resource requirements. The management system, which could be integrated with the cloud orchestration platform, plays a vital role in monitoring the server's response time and making decisions regarding the deployment or termination of Proxy and Cache instances.

Similar to cloud management, the management of the Proxy and Cache instances follows principles of scalability and flexibility. The system can scale up or down based on the workload and user demands, ensuring optimal performance and resource utilization. Cloud management practices can serve as a reference for managing the Proxy and Cache components, but further exploration and research in this area are needed.

Of particular note to address the scalability issues mentioned in Section II, the CDCA architecture deploys many Proxy and Cache instances horizontally to assure a desired response time for any user by taking an integrated distributed Proxy approach to solve the unique Proxy limitation of the Chandra et al. proposal [11]. This CDCA approach directive offers several advantages in utilizing NFV in real-time network orchestration, particularly in optimizing runtime processing, transfer times, and scalability. Here are some benefits of using NFV in this context:

*1) Flexibility and agility*: NFV enables the virtualization of network functions, allowing them to be deployed and scaled as needed. This flexibility enables dynamic resource allocation and efficient utilization of infrastructure based on the current workload. It allows for quick deployment and adjustment of network services, leading to improved agility in responding to changing network demands.

*2) Scalability*: NFV provides scalability by allowing network functions to be dynamically instantiated and scaled according to the workload. During peak times, when network traffic is high, additional instances of network functions can be provisioned to handle the increased load, ensuring smooth operation and optimal performance. Similarly, during low-traffic periods, unnecessary instances can be scaled down or deactivated, saving resources.

*3) Resource optimization*: NFV allows for efficient utilization of hardware resources by consolidating multiple network functions onto virtualized infrastructure. This consolidation eliminates the need for dedicated hardware for each network function, leading to cost savings and improved resource utilization. Additionally, NFV enables the sharing of resources among different network functions, optimizing resource usage based on demand.

*4) Faster deployment and service innovation*: NFV decouples network functions from proprietary hardware, allowing them to run on general-purpose servers or cloud infrastructure. This decoupling simplifies the deployment process and reduces the time required to introduce new services or update existing ones. It enables service providers to rapidly deploy and scale network functions, promoting faster innovation and time-to-market for new services.

*5) Cost efficiency*: NFV can result in cost savings by reducing the need for expensive proprietary hardware appliances. Instead, virtualized network functions can be run on standard servers or cloud infrastructure, which are typically more cost-effective. NFV also enables service providers to adopt a pay-as-you-grow model, scaling their infrastructure based on actual demand, thereby optimizing costs.

By leveraging NFV in real-time network orchestration, service providers can achieve optimum runtime processing, reduce transfer times, and achieve high scalability, allowing them to efficiently handle variable network workloads and provide a better quality of service to their users.

Overall, the CDCA architecture aims to provide a scalable and manageable solution by exploiting distributed SDN controllers, dynamic deployment of Proxy and Cache instances, and integration with cloud orchestration platforms. Future work can delve deeper into the management aspects,

drawing inspiration from cloud management practices to enhance the efficiency and effectiveness of the system.

Algorithm 1 gives the core logical idea behind the operational aspects of the CDCA architecture, describing how the Proxy and Cache instances work together. Both components have a specific task in the processing of user requests. The Proxy is responsible for identifying and deciding *where* and *which* requests are going to be cached, while the Cache is responsible for providing the storage resources in order to Cache the contents according to the network policy. The details of the operational aspects of each component are described in the next subsections.

---

**Algorithm 1:** CDCA architecture operation

---

**1** The user triggers a content request;

**2** The SDN Controller forwards the request to the closest Proxy *cPrx*;

**3** *cPrx* checks its shared index if there is a content copy under its domain;

**4 if** *there is a content copy* **then**

**5**     *cPrx* forwards the request to the Cache *cCh* thatholds the content copy;

**6**     *cCh* delivers the cached content to the user;

**7 end**

**8 else**

**9**     *cPrx* forwards the request to the closest Cache *cCh*;

**10**     *cCh* retrieves the content from the original ContentServer;

**11**     *cCh* delivers the content to the User;

**12**     *cCh* stores the content for next User;

**13**     *cCh* notifies *cPrx* that a new content has beencached;

**14**     *cPrx* updates the index;

**15 end**

---

### A. Content Forwarding

The dependency on the SDN infrastructure in the CDCA solution for content dispatching offers several advantages, particularly in terms of efficiency and transparency. Some key points related to this dependency:

*1) Transparent request forwarding*: SDN allows for the transparent forwarding of content requests to cacheable content and Proxy instances on the network. By leveraging the OpenFlow protocol or similar SDN technologies, it becomes possible to create traffic flows on the switches that map specific TCP or UDP ports of applications. This enables the SDN Controller to direct requests to the appropriate Cache or Proxy without modifying the IP packet header. This transparency ensures that the communication between clients and the requested content or Proxy remains seamless and unaffected.

*2) Efficient traffic steering*: With the help of SDN, traffic can be efficiently steered to the desired destinations. By leveraging the programmability and control capabilities of SDN, the SDN Controller can dynamically analyse network conditions, load distribution, and Cache availability to make intelligent decisions on how to direct traffic. This enables the system to optimize content delivery by sending requests to Cache instances or the closest Proxy, minimizing latency and improving overall network performance.

*3) Flexibility and adaptability*: The use of SDN provides flexibility and adaptability to the solution. Since the forwarding, behaviour of switches can be dynamically controlled by the SDN Controller, changes in the network topology or caching infrastructure can be easily accommodated. New Cache instances or Proxy nodes can be added, removed, or reconfigured without requiring changes in the underlying network infrastructure. This flexibility allows the solution to scale and adapt to changing demands and evolving network conditions.

*4) Enhanced network visibility and control*: SDN offers centralized network management and control, providing enhanced visibility and control over network traffic. By having a centralized SDN Controller, network administrators can monitor and manage content dispatching, Cache utilization, and overall network performance from a single point of control. This centralized control enables efficient decision-making and troubleshooting, leading to improved network efficiency and performance.

Typically, the SDN infrastructure for content dispatching brings efficiency, transparency, flexibility, and enhanced control to the CDCA solution. By using SDN technologies like the OpenFlow protocol, it becomes possible to transparently forward requests to cacheable content and Proxy instances on the network without the need to modify IP packet headers. This enables efficient traffic steering and dynamic adaptability, leading to improved content delivery and network performance.

In the CDCA architecture, two approaches are used for creating flows in the SDN switches: proactive and reactive [15]. Here are the characteristics and considerations associated with each approach:

*1) Proactive approach*: In the proactive approach, the OpenFlow Controller configures all the necessary flows from the users to the nearest Proxy instance before any request is made to a server. This means that the flows are pre-installed in the switches based on anticipated traffic patterns. The advantage of this approach is that it avoids the need for switches to request the Controller for each new flow, thereby reducing forwarding delay. However, one drawback is that all data packets are routed through the same network segment or domain path, which can potentially lead to congestion on that path.

*2) Reactive approach*: In the reactive approach, flows are created on-demand, meaning that they are installed in the switches only when a request is made by a user. When a switch receives a packet for which there is no pre-installed flow, it sends a request to the Controller, which then installs the appropriate flow and forwards the packet accordingly. This approach introduces some latency as switches need to

contact the Controller for each new flow. However, it provides the opportunity to use load-balancing techniques to set alternate paths, thereby reducing congestion and improving network performance.

In the CDCA architecture, the Controller sets a path to the nearest Proxy instance in a reactive manner, meaning that flows are installed on-demand as requests are made by users. This allows for dynamic path determination based on the current network conditions and load distribution. On the other hand, the path from the user to the Cache or external network is set proactively, meaning that the necessary flows are pre-installed to optimize the forwarding of user traffic. This proactive approach helps minimize latency and optimize link usage. Remember that the NFV module establishes a new path for each new user request, providing scalability and load balancing.

By combining the proactive and reactive approaches, the CDCA architecture aims to achieve an efficient and balanced network operation. The reactive approach mapping users' requests to the nearest Proxy minimizes latency by dynamically determining the optimal path based on current network conditions. Meanwhile, the proactive approach setting the path from the user to the Cache or external network to ensure efficient forwarding without switches requires the Controller the path for each new flow [15].

It is important to note that the choice between proactive and reactive approaches may depend on specific network conditions, traffic patterns, and performance requirements. Both approaches have their advantages and trade-offs, and the decision should be made based on the specific needs and constraints of the network deployment.

When the SDN Controller receives an HTTP request, it sets a flow from the user to the Proxy. The forwarding is based on the destination IP address, i.e., the Content Provider IP, destination HTTP port (typically port 80) and the user's IP address to select the best Proxy to be used, e.g., closest to the user. The Proxy element is necessary because the SDN only analyses IP header fields, not HTTP requests. The Proxy analyzes the HTTP GET header and checks if the content is cached in its DHT index table. Then, it forwards, i.e., sets the flow in network switches, to connect the user to Cache. From this moment onwards, the user interacts only with the Cache until a new request is done, minimizing Proxy processing. In big content delivery, e.g., VoD services, a user maintains a long-time connection with a Cache.

Once a request arrives at a Proxy, it performs a deep inspection of the request to decide to which Cache this request should be forwarded. This inspection is possible for requests using the HTTP protocol, as the packet payload can be read by the Proxy. However, for requests using the HTTPS protocol, which provides encryption and security, performing deep inspections on the packet payload is not feasible and would risk breaching security.

When the Proxy needs to determine the path from the user to the closest Cache, it sends a command to the SDN Controller using a Representational State Transfer (REST) Application Programming Interface (API). The API allows the Proxy to communicate with the SDN Controller and provide the necessary information to install the required flows on the switches that belong to the network path connecting the user to the closest Cache.

This process of sending commands to the SDN Controller and installing flows on the switches ensures that the traffic is directed efficiently and transparently, optimizing the content delivery process. Fig. 2 provides an illustration of this timeline flow process, highlighting the interactions between the Proxy, SDN Controller, and switches in the network path as follows:

*1) Content request identification*: The SDN Controller identifies content requests from users within the network.

*2) Forwarding to proxy*: The SDN Controller forwards the content requests to the Proxy component responsible for handling Cache-related operations.

*3) Checking cache availability*: The Proxy checks if the requested content is already cached within the network.

*4) Forwarding to cache*: If the content is already cached, the Proxy forwards the request to the appropriate Cache instance that stores the content. This allows for direct content delivery from the Cache to the user.

*5) Flow path configuration*: The SDN Controller configures a data flow path from the Cache to the user, establishing a direct transmission route for efficient content delivery.
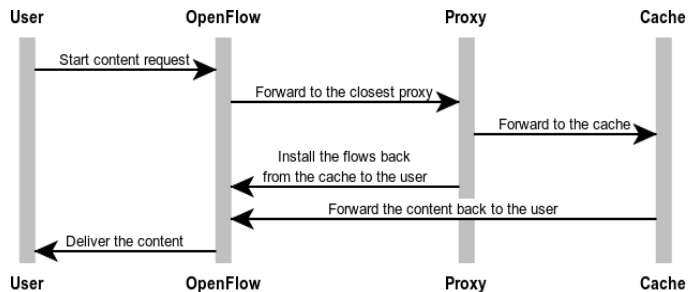


Fig. 2. Content forwarding sequence flow steps.

The CDCA approach ensures a transparent Cache handling for users without requiring any changes to their application implementations. The underlying transport protocol, TCP, necessitates that both the Proxy and Cache nodes are aware of connection handling details, as the connection state needs to be exchanged between them by SDN Controller that knows all Cache and clients address [16]. This awareness allows for the seamless transfer of connections from the Proxy to the Cache.

The use of SDN in implementing a transparent forwarding mechanism is also discussed in the work by Koulouzis et al [17]. Their research focuses on enhancing the transfer of data-intensive scientific applications by leveraging SDN network programmability.

By incorporating SDN principles and applying the REST API and SDN architecture, the CDCA architecture enables dynamic and controlled flow management, allowing for efficient content caching and delivery while respecting security considerations and the limitations imposed by the HTTPS protocol.

The release of HTTP/2 introduces improvements and new challenges to the Web. Its specification was published in May 2015 [18], and its adoption has been growing. The HTTP/2 decreases latency and improves web browsers' load speed and video delivery by implementing many new features [19]: (1) compression of HTTP headers; (2) inclusion of HTTP/2 Server Push; (3) multiplexing and pipelining of multiple requests over a single TCP connection; and, (4) fixing of blocking problem in HTTP/1.1. The HTTP/2 specification recommends cryptography using TLS 1.2, but it is not mandatory. For video streaming, HTTP/2 Server Push relieves the Proxy processing, and the video chunks should be delivered unencrypted to reduce the encryption overhead of video files.

The CDCA architecture supports HTTP/1.1 and HTTP/2 offering seamless smooth ambiance effect video viewing without side effects, because the request are initiated at the client side. In HTTP/1.1, with no Server Push, the performance is lower than HTTP/2. In general, most of the contemporaries, like CDCA researcher, consider encrypted video to be unfeasible for normal viewing because each browser would need a different crypt-key per connection. However, if cryptography is required for whatever reasons, CDCA system is easily capable of providing any publicly available standard encryption/decryption module such as a Deep Packet Inspection (DPI) module, which will be addressed in another article.

Content identification is the initial most important task performed in the Proxy. The architecture does not Cache all kinds of information, but only large and reusable content, e.g., video and music on demand, software installers, or sizable images.

The most important, big, and reusable content object application on the Internet is VoD. A plethora of VoD providers exist. All of them use similar approaches to provide a variety of content delivery services. Most of them use Flash and HTML5 as video player. In the CDCA experiment, HTML5 was chosen since it is better for identifying video characteristics. The video stream encoder is mostly H.264/MPEG-4, and the video stream is not encrypted to reduce server and client overhead. This fact is very important for the CDCA architecture because there are some outstanding security issues regarding encrypted content, which should be readable only by the first user. And, of course, we suppose the multimedia videos are royalty-free to permit distribution to all users, which, in reality, might be different in business-oriented provider networks with regard to payment to owners of the content or to their nominated agents, such as the service provider.

Currently, the transport protocol for video streaming on the Internet is accomplished by using either TCP or UDP. The delivery of live video streaming with *on-the-fly* encoding, like IPTV, is mostly UDP based, but the delivery of pre-encoded video, called VoD, essentially uses TCP [20]. In the CDCA architecture, the focus is on VoD services over TCP. For the evaluation, YouTube is considered since it is the most prominent VoD portal, which handles more than several billion video streams daily. While the YouTube site itself operates over HTTPS, the actual video stream requests and delivery are performed using HTTP. This allows for the identification of unencrypted HTTP requests and the corresponding HTTP objects are easily identified using pattern-matching techniques [21]. It is worth noting that the architecture is designed to handle TCP-based VoD services and can be adapted to support other VoD providers with minor modifications. The future intention is to analyze and adapt the CDCA solution for various VoD platforms, applying the same approach used for YouTube.

For instance, considering a YouTube video URL, the web page provides the link for different formats, e.g., *href="http://www.youtube.com/watch?v=yXc8KCxyEyQ"* for standard format, *href="http://m.youtube.com/watch?v=yXc8KCxyEyQ"* for hand-held devices, and also for specific devices, like Android, *href="android-app://com.google.android.youtube/http/www.youtube.com/watch?v=yXc8KCxyEyQ"*.

It seems that Google implements some techniques to restrict the direct access to video in a lot of ways. It is possible to see some interesting fields in the URLs, e.g., "?part=" and "?range=," which permit identifying of each downloaded chunk and storing it in the correct order. The process to retrieve a Youtube video requires reverse engineering to extract chunk information from the URL, a technique used by some "Youtube downloaders", which is very common nowadays.

YouTube employs various mechanisms, including DNS translation and URL redirection, to optimize the delivery of video content. These mechanisms help distribute the video's chunk files across multiple caching servers, allowing for load balancing of the transmission.

The YouTube video delivery name is composed of three key components [22]:

*1) Video ID space*: Each video on YouTube is assigned a unique video ID, which serves as an identifier for the specific video content.

*2) Hierarchical logical video server*: YouTube utilizes a hierarchical logical video server structure to organize and manage video content. This structure helps ensure efficient content management and delivery across the platform.

*3) Physical server cache hierarchy*: The physical server Cache hierarchy represents the distribution of caching servers used by YouTube. The chunk files of the videos are stored in these caching servers, which are strategically located to optimize content delivery and minimize latency for users.

By employing DNS translation, URL redirection, and a well-structured video delivery name, YouTube can efficiently distribute and deliver video content, providing a seamless streaming experience to its vast user base as:

*a) YouTube Video Id Space:* Each YouTube video is uniquely identified using a fixed-length flat identifier with random (nonsensical) characters, e.g., something like *yXc8KCxyEyQ*.

*b) Hierarchical Cache Server DNS Namespaces:*

YouTube defines multiple DNS namespaces representing a group of logical video servers related to the video format and resolution. The DNS namespace forms a hierarchical structure of logical video servers that are mapped to an IP address where the video file is stored, e.g., http://b8u-4vge.googlevideo.com

*c) Physical Cache Servers:* In the case of YouTube, the logical Cache servers are represented by a unique logical namespace in the DNS names. However, each DNS resolution of this namespace can map to a large set of IP addresses, which correspond to the physical Cache servers. For example, if we consider the hostname *http://b8u-4vge.googlevideo.com,* the primary namespace represents the logical Cache server. However, depending on factors such as the user's location and the load balancing policy in place, multiple IP addresses can be associated with this hostname. These IP addresses correspond to the physical Cache servers that store and serve the video content.

YouTube uses HTTP to deliver videos to users in order to reduce the cryptography overheads. Even under an HTTPS connection, the HTTP request can be easily seen. Analyzing the URL, we can identify the video name (Video Id Space) and the format and resolution for a specific device (Hierarchical Cache Server DNS Namespaces). In the CDCA architecture, the *Physical Cache Server* component does not give away any useful information.

### B. Proxy Design

The Proxy component acts as an intelligent intermediary between users and Cache nodes, ensuring efficient content delivery and load balancing within the network. It plays a crucial role in the CDCA architecture as it handles users' requests and ensures the delivery of the requested content to the nearest available Cache. Its main function is to determine the appropriate Cache node to serve the content based on a mapping index.

When a user makes a content request, the Proxy checks whether there is an existing copy of the requested content in the network. If a copy is available, the Proxy forwards the request to the Cache node that holds the content. This minimizes the latency and improves the response time for the user. In cases where the requested content is not available in any Cache node, the Proxy identifies the Cache node closest to the user and forwards the request to that node. This Cache node becomes a aspirant for holding a copy of the requested content. If there are multiple Cache nodes with the same distance from the user, the Proxy employs a round-robin operation. This load-balancing technique distributes the requests among the Cache nodes equally, ensuring efficient utilization of resources and preventing any single Cache node from becoming overloaded.

Since it is possible that many Proxies exist over the network, each Proxy instance participates in a DHT to share the content index. This DHT serves as a Distributed Forwarding Unit (DFU) that allows efficient content lookup and forwarding among the proxies.

While there are multiple Proxy instances distributed throughout the network, it is important to note that each user's requests will always be handled by the same Proxy node nearest to it. This selection of the closest Proxy node to the user ensures proximity-based routing and minimizes latency in the content delivery process.

By maintaining the user's requests consistently routed to the same Proxy node, it offers several advantages. Firstly, it provides a predictable and reliable user experience as the user interacts with the system through a specific Proxy node. Secondly, it allows the Proxy node to maintain the context and state of the user's requests, facilitating personalized content delivery and improving overall efficiency.

The sharing of the DHT among the Proxy instances enables efficient content indexing and lookup. When a user request arrives at a Proxy node, it can quickly query the DHT to determine if the requested content is available in the network and identify the Proxy node that holds a copy of the content. This ensures effective content retrieval and delivery to the user.

The forward decision is taken by the SDN Controller that receives the network state information from the network management system, choosing the best Proxy instance. Because any new user's request is processed by the SDN Controller, it should choose the optimal Proxy *on-the-fly* based on the network status. Generally, the closest Proxy will be the perfect solution because it will have the minimum delay. It also does not store any content and only looks at a DHT table. However, if one Proxy processes more requests than another, it is possible to redirect the requests to load balance the system considering network and server status.

The Proxy and Cache instances maintain a virtual overlay network configuration schema, which enables them to exchange Cache states and commands seamlessly. When a Proxy decides to forward a user's request to a Cache instance, it sends a command to the chosen Cache, specifying the request and the user. This command instructs the Cache to serve the requested content to the user.

Upon sending the command, the Proxy listens for an acknowledgment from the Cache. This acknowledgment confirms that the content has been successfully cached by the Cache instance. It allows the Proxy to update its index, which maps content names to Cache instances. This updated index enables the Proxy to efficiently forward future requests for the same content to the same Cache instance, enhancing caching effectiveness and reducing content retrieval latency.

Additionally, the acknowledgment may provide information about the content's lifetime. The Cache instance specifies the maximum duration for which the content will be cached. Once the Cache lifetime expires, the corresponding index entry for the content is automatically removed from the DHT, ensuring that outdated content is not unnecessarily stored in the network.

By maintaining an efficient and synchronized index across Proxy and Cache instances, the architecture optimizes content caching, improves content availability, and ensures that the most relevant content is stored and served efficiently.

The content caching mechanism is designed to be transparent and efficient, allowing any Proxy to forward a request to a Cache instance that already holds the requested content. This means that even if a Proxy is responsible for managing a specific Cache instance, it can still forward requests to other Cache instances that have the desired content.

As an example, for instance, where Proxy 'A' manages Cache 'A' and Proxy 'B' manages Cache 'B', if a user near Proxy 'A' requests content 'C', Proxy 'A' would handle the request. However, since Proxy 'A' knows that Cache 'B' has a copy of content 'C' (as indicated by the DHT index), it would forward the user's request to Cache 'B' to fetch the content. This behaviour enables efficient utilization of the caching infrastructure, as any available Cache instance can serve content to users, regardless of the Proxy managing it, thus optimizing content retrieval and delivery, ensuring that users can access the content efficiently from the nearest available Cache instance. This approach enhances the overall performance of the caching system and improves user experience.

Usually, choosing the optimal Cache or deciding to fetch content from an external server is most desirable in content delivery systems. The choice between fetching content from an in-network Cache or from an external server depends on various factors, such as Cache proximity, network conditions, content availability, and delivery requirements.

In the CDCA architecture, the decision of whether to fetch content from an in-network Cache or from an external server is not explicitly addressed. However, future works and research can focus on developing intelligent policies or algorithms to determine the best Cache to use within the network or when it is more efficient to fetch content from an external server. These policies could take into account factors such as Cache proximity, network congestion, content popularity, Cache availability, and other performance metrics. By considering these factors, the system can dynamically adapt and make better decisions based on the current network conditions and optimize content delivery for the best user experience.

Overall, this Proxy design scheme enhances the scalability, reliability, and performance of the CDCA architecture.

### C. Cache Design

The Cache component plays a vital role in serving user requests and optimizing content delivery. When a request reaches a Cache instance, it first checks its local memory using a Hash Table for the fast lookup to see if the requested content is already stored. If the content is found in the Cache, it can immediately send the requested content back to the user through the previously configured OpenFlow path. This enables fast and efficient delivery of content from the Cache without the need to retrieve it from the original server.

However, if the content is not available in the Cache, the Cache acts as a Proxy and forwards the user's request to the target server specified in the request. This behaviour is similar to a standard client-server interaction without caching. When the target server responds to the request, the Cache immediately sends the response back to the user.

Additionally, the Cache performs a deep packet inspection on the response received from the target server. This inspection helps determine if the response is cacheable or not. The Cache examines the nature of the protocol being used (such as HTTP) and looks for specific headers, like the Cache-Control header in the case of HTTP. The Cache-Control header provides instructions to consumers (in this case, the Cache) on how the response can be cached, including the duration for which it can be cached or whether caching is prohibited by the server.

When the Cache determines that the fetched content is cacheable, it immediately notifies the Proxy that it now holds a copy of the content. This ensures that subsequent requests for the same content can be efficiently served from the Cache. Additionally, the Cache may include a Cache lifetime value, which indicates the maximum duration for which the content should be considered valid in the Cache. The determination of the Cache lifetime value depends on the characteristics of the media, such as its freshness requirements or expiration policies.

In cases where the content is deemed non-cacheable, such as very small content that may not benefit from caching, the Cache simply sends the response directly to the user without storing it. This prevents unnecessary utilization of Cache space and avoids the need for DHT updates related to that particular content.

Setting the Cache lifetime value appropriately is crucial for optimizing system performance. It allows balancing between serving stale content and the overhead of fetching fresh content from the server. The specific Cache lifetime values and policies can be defined by the content provider according to their own requirements and policies.

### D. Cache Management

Separating the data storage layer from the control function of Cache instances offers flexibility and scalability in the deployment of the caching system. By decoupling these two functions, each Cache instance can operate independently without interfering with the others in the storage layer.

This separation allows for various deployment scenarios, each with its own characteristics. For example, multiple Cache instances can be deployed on different physical servers or virtual machines, enabling distribution across different geographical locations or network segments. Each Cache instance can have its own storage resources, such as disk space or memory, dedicated to serving content requests. For instance, an ISP may deploy a number of caches over their network, configuring 70% of the instances to use their RAM memory while the other 30% are configured to use SSD disks. The decision about the type of storage that will be used by the Cache instances and where they are deployed is a decision that must be taken by the network operator since there are many strategical decisions involved.

The separation of data and control also enables the implementation of different caching strategies or policies within each Cache instance. This means that each Cache

instance can have its own set of rules and algorithms for content eviction, replacement, or caching optimization, tailored to specific requirements or objectives, allowing for efficient and independent operation of each Cache instance within the caching system.

The decision of whether to store content in memory or on local disks within a Cache instance is an important aspect that can significantly impact caching performance and efficiency. Both options have their advantages and considerations.

Using an in-memory approach provides faster access to cached content due to the high speed of memory. It is particularly suitable for frequently accessed or hot content that requires low-latency delivery. However, memory capacity is typically limited compared to disk capacity, which means that the Cache can store a smaller amount of content in memory. This can lead to a higher likelihood of Cache eviction for less frequently accessed or cold content, resulting in potential Cache misses and increased latency.

On the other hand, storing content on local disks provides a larger storage capacity, allowing the Cache to accommodate a larger volume of content. This is advantageous for caching less frequently accessed or larger files. Disk-based storage can be especially useful for VoD (Video on Demand) services that deal with pre-encoded videos, where the content size can be substantial. However, accessing content from disks is generally slower compared to memory, which can introduce additional latency.

The choice between in-memory and disk-based storage depends on various factors, including the nature of the content, the expected workload, and the network administrator's policy. If the network administrator prioritizes fast access to frequently accessed content, an in-memory approach might be preferred. Conversely, if accommodating a larger volume of content is crucial, disk-based storage is more suitable.

Additionally, the eviction policy is an essential consideration in Cache design. It determines how content is selected for eviction when the Cache reaches its capacity limit. There are various eviction algorithms, such as LRU (Least Recently Used), LFU (Least Frequently Used), and Random Replacement, each with its own trade-offs in terms of Cache efficiency and performance. The network administrator can choose the most suitable eviction algorithm based on factors such as content popularity, access patterns, and the desired Cache hit rate.

The CDCA architecture is flexible such that it can be configured to use any eviction algorithm by an open API, i.e.; the network administrator can choose the best algorithm according to the user's profile. Cache eviction policies are well discussed in Balamash [23] and Wang [24].

It is possible to use a hybrid approach when dealing with the decision to store the content in memory or on disk. For instance, a hybrid approach combining both memory (M1) and disk (M2) storage can provide a balance between fast access and larger storage capacity. This approach takes advantage of both memory and disk to optimize caching performance.

In the hybrid approach, frequently accessed or hot data is stored in the M1 Cache, which is the faster memory component. This ensures that popular content is readily available for fast retrieval and reduces latency for frequently requested items. The M1 Cache acts as a high-speed Cache tier that can quickly serve content without accessing the slower disk storage.

On the other hand, less frequently accessed or cold data is stored in the M2 Cache, which resides on a disk. The M2 Cache provides a larger storage capacity compared to memory, allowing the Cache to accommodate a broader range of content. Although accessing content from the M2 Cache may introduce additional latency, the presence of frequently accessed items in the M1 Cache minimizes the impact on overall performance.

To optimize the hybrid approach, a managing schema algorithm is employed to determine which data should reside in the M1 Cache and which should be stored in the M2 Cache. This algorithm can monitor access patterns, frequency of requests, and other relevant metrics to make informed decisions about data placement. For example, if a content item in the M2 Cache starts to experience increased access frequency, the managing schema algorithm can dynamically promote it to the M1 Cache to improve access time.

The reconfigurability of the Cache instance is a valuable feature that allows for dynamic adjustments and fine-tuning of the Cache's parameters to meet changing demands and optimize performance. By deploying the Cache instance within a Virtual Machine (VM), it becomes possible to modify various aspects of the Cache configuration during runtime.

One such configurable parameter is the storage capacity, which includes both memory and disk space. As the workload increases and the Cache approaches its capacity limit, it may become necessary to adjust the available storage resources to accommodate additional data. This can be achieved by dynamically increasing the memory allocation or expanding the disk space assigned to the Cache VM.

In addition to storage capacity, other parameters such as eviction policies can also be tuned. The eviction policy determines which content items are evicted from the Cache when it reaches its capacity limit. By adjusting the eviction policy, the Cache manager can prioritize certain content or employ different strategies to optimize Cache utilization and improve hit rates.

When the Cache becomes saturated and the eviction rate surpasses a predefined threshold, the Cache manager can take proactive measures to address the situation. This may involve automatically attaching a new VM to distribute the caching load, increasing the available memory to accommodate more content in the M1 Cache, or modifying the eviction policy to better manage the Cache's content.

The ability to make such adjustments dynamically (on-the-fly) and in a dynamic manner allows the Cache instance to adapt to varying workloads and optimize its performance in real time. This flexibility ensures that the Cache can efficiently handle increasing demands and effectively utilize available resources, ultimately enhancing the overall

efficiency and responsiveness of the caching system.

*E. Cache Policy Management*

Designing a system that can cater to various business needs and network traffic patterns requires careful consideration of policy management. Different organizations and network environments may have specific requirements, priorities, and constraints that need to be taken into account. Therefore, the system project incorporates design strategies to enable efficient content delivery while also accommodating complex real-world policies.

Policy management encompasses various aspects, including caching policies, eviction policies, load balancing policies, content placement policies, and more. These policies define how the system operates, makes decisions, and prioritizes tasks. By incorporating flexibility in policy management, the system can be customized and tailored to meet specific requirements.

One important design strategy is to provide configurable parameters and APIs that allow administrators or users to define and modify policies according to their needs. This flexibility empowers organizations to adapt the system to their unique business rules and network traffic patterns. For example, administrators can define caching policies based on content popularity, user preferences, or other relevant factors.

Furthermore, the system project may offer a range of pre-defined policy templates or algorithms that serve as a starting point for administrators to choose from. These templates can be based on industry best practices or research findings, providing guidance for policy selection. Administrators can then fine-tune and customize these templates to align with their specific requirements.

Additionally, the system may provide monitoring and analytics capabilities to gather data on network traffic, content usage patterns, performance metrics, and other relevant information. This data can be used to evaluate the effectiveness of existing policies and make informed decisions for policy adjustments or optimizations.

By considering policy management as an integral part of the system design, the project aimed to provide a flexible and adaptable solution that can cater to diverse business needs and network scenarios. This approach acknowledges that different organizations may have unique policies and requirements, and it offers the means to configure and manage these policies effectively to achieve optimum performance and content delivery outcomes.

The policy management function being performed on the Proxy component is a logical and efficient choice. As the decision-maker responsible for managing a set of caching instances, the Proxy is well-positioned to handle policy management tasks. Since all requests from a subset of network nodes pass through the Proxy, it has the necessary visibility and control to implement and enforce caching policies effectively.

By extending the Proxy's content inspection capabilities, it becomes possible to deeply analyse the content's data and incorporate manageable aspects into the policy management process. This allows the Proxy to make intelligent decisions about which content should be cached based on specific criteria or conditions.

In the current stage of proposal development and experimentation, the system has addressed five caching policies to provide adaptability to different workloads commonly encountered in practice:

*1) Cache everything*: This policy implies caching all content without any specific filtering or criteria. It ensures that all requested content is stored in the Cache for future retrieval.

*2) Cache only content whose name matches any given regular expression set*: This policy allows administrators to define a set of regular expressions to match content names. Only content with names that match these expressions will be cached, while others will be bypassed.

*3) Cache only content whose size matches certain file criteria*: This policy focuses on caching content based on their file size. Administrators can define specific criteria (e.g., minimum or maximum file size) to determine which content should be cached.

*4) Cache only content served by a specific set of target domains*: This policy restricts caching to content served by designated domains. Administrators can specify a list of target domains, and only content from these domains will be eligible for caching.

*5) Cache-only content of a given type (audio, video, etc.)*: This policy enables selective caching based on content types. Administrators can specify the types of content (e.g., audio, video, images) that should be cached, while excluding others.

The system utilizes a pipeline processing approach to handle multiple sets of distinct policies in an efficient manner. This approach allows the policies to be applied in a combinatorial fashion, starting from the most restrictive to the least restrictive that serves as a set of policy filters to derive an optimal management solution.

When a request reaches the Proxy, it undergoes a deep inspection phase to gather relevant information about the content. Following this, the request is processed through the policy pipeline, which consists of sequentially applying the defined policies to determine whether the content should be cached or not.

The policy pipeline filters the requests based on the defined rules, allowing or denying caching of the requested content. If a request is denied by any policy rule in the pipeline, the Proxy sends a forward command to the Cache instance without expecting Cache confirmation or acknowledgment. In this case, the content will have a flag indicating that it cannot be cached by that specific Cache instance.

The algorithm presented in Algorithm 2 serves as an example of how the policy pipeline operates for Caching, determining the caching behaviour based on the policies:

*1)* Initialize the request
*2)* Perform deep inspection on the request

*3)* Set caching_allowed = True

*4) For each policy in the policy pipeline*: a. Apply the policy rule to the request b. If the policy denies caching: - Set caching_allowed = False - Break the pipeline loop

*5) If caching_allowed is True*: a. Forward the request to the closest Cache instance to the user b. Expect Cache confirmation/acknowledgment

*6) If caching_allowed is False*: a. Send a forward command to the Cache instance b. Set the content's "*cacheability"* flag to indicate no caching

By processing requests through this policy pipeline, the system can effectively filter and determine the caching behaviour based on the defined policies. The pipeline approach allows for flexible and customizable policy management, enabling administrators to derive an optimal caching solution based on their specific requirements and policies.

In some cases, certain requests cannot enter the processing pipeline until they have been served by the originating server. For example, in HTTP requests, the requester may allow the receipt of both text and video responses, but the actual response will determine the content type by inspecting the ContentType header. Similarly, the content's size may not be known until the response has been completely received.

In such cases, the same processing pipeline can be applied at the Cache instances, but only in specific scenarios where the request can be fully inspected and the necessary information is available. The Cache instances can run the policy pipeline to determine the caching behaviour based on the received response.

It's important to note that if the Proxy's flag command allows caching, it prevents the Cache from overriding any previous decision made by the Proxy. This ensures that the caching behaviour determined by the Proxy is maintained and not altered by the Cache instances.

By allowing the processing pipeline to run at both the Proxy and Cache instances, the system can ensure consistent caching decisions and policies across the network, taking into account the specific characteristics and information available at each stage of the request-response cycle.

---

**Algorithm 2:** Policy processing method

**Data:** The content request *cRqst*; and a set of filters *polFltr[]*

**Result:** 1 if the content should be cached, 0 otherwise

1 **foreach** *p in polFltr[]* **do**
2     **if** *p(cRqst) == 0* **then**
3         **return** 0;
4     **end**
5 **end**
6 **return** 1;

---

*F. System Scalability*

Scalability is a crucial aspect of the CDCA architectural system, and it involves the SDN Controller, proxies, and caches. To ensure scalability and address availability concerns, the architecture allows for the deployment of new instances of these components in the network on the fly. One key factor in achieving scalability is the use of a stateless OpenFlow control. This enables simple load balancing across multiple Controller devices, ensuring that the control plane can handle increasing demands and distribute the workload effectively [9]. By distributing the control plane functionality, scalability and redundancy are improved, as multiple controllers can handle the control tasks in a distributed manner. In the context of SD-ICN, scalability becomes an even more significant concern due to the introduction of in-network caching and content-based communication. To address the control plane scalability challenge, Gao et al. propose the Scalable Area-based Hierarchical Architecture (SAHA) [25]. SAHA is designed to handle the control plane scalability problem specific to SD-ICN environments and provides a hierarchical architecture that enables efficient management and scalability.

Several distributed architectures have been CDCA to enhance OpenFlow scalability and redundancy. Examples include Disco [26], ElastiCon [27], and Onos [28]. These architectures aim to distribute control plane functionality, improve scalability, and provide redundancy mechanisms to ensure high availability.

By leveraging these scalable and distributed architectures, the CDCA system can handle increasing demands, distribute control tasks effectively, and provide redundancy to ensure system availability. This enables the system to accommodate a growing number of users, requests, and caching instances while maintaining efficient control plane operations.

Analyzing the Proxy design, it is possible to notice that its main idea is to simply forward the request to the appropriate Cache, thus it relies on the DHT index to get all information it needs about the caching state, which is spread over all Proxy instances of the network topology. The most costly operation that the Proxy does (determine where content was previously cached) basically relies on a DHT lookup operation, which is the operation that can constrain the Proxy scalability. Since the chosen DHT implementation is in conformance with Chord [29], a lookup operation needs just $O(logN)$ messages to find any key in the table and $O(log^2N)$ messages to update any key, where $N$ is the number of proxies deployed in the network. While the Proxy relies on a DHT to find the appropriate Cache to forward requests, the Cache itself is a simple solution that only relies on a Hash Table to look up cached contents locally, so all its operations require $O(1)$ time. The main concern about the Cache is simply its memory capacity, which obviously will limit the amount of data that can be stored in that network node.

Along with the individual characteristics of each component, the overall architecture is also important. The decision of using a microservice architectural pattern was furthermore taken based on the scalability opportunities that such design offers. Many modern systems built incloud environments take this same direction when scalability is a major nonfunctional requirement. The main characteristic of microservices comes from its own definition, which states that a microservice should do one thing, and do it well. Such an

idea allows that a system with multiple functional components can be developed, tested and deployed separately. It makes easy as operational actions that must be taken in response to business and network requirements. The CDCA solution has these characteristics, allowing, for instance; the number of proxies, caches, or controllers can be changed over time independently of each other to satisfy any demand.

The CDCA architecture has been designed with flexibility in mind, and considering how the architecture's components could be used and reused in real-world production provider networks. The architecture considers the business needs, the technical issues, and the most important constraints that concern network providers on a daily basis. As previously mentioned, the idea to use SDN and NFV brings several deployment possibilities, and the architecture has been designed to accommodate these different deployment possibilities. The network administrator can deploy the system according to the exact business and technical needs. The idea is to create autonomous *islands* responsible for handling the in-network content caching in a specific network segment/domain. These islands may contain several Cache instances and few Proxy instances, each of them operating independently, yet sharing the same data content across the DHT index at the proxies. The network segment/domain could be composed of any arbitrary set of users and/or network devices, each of them sharing common features, like geographical region, traffic patterns, etc.

## V. RESULT ANALYSIS OF THE CDCA SYSTEM

The experiments have been conducted to evaluate the effectiveness of the CDCA architecture and prototype operational system. By conducting these experiments, one can gain valuable insights into the performance, scalability, and feasibility of deploying the system in real-time production networks.

Evaluating the system in a realistic environment helps identify any potential challenges, bottlenecks, or areas for improvement. It also allows you to gather empirical data on the system's performance, such as response times, caching efficiency, and resource utilization. By conducting experiments and gathering insights, one can refine and optimize the CDCA architecture, ensuring that it meets the requirements and expectations of real-world deployment scenarios. Additionally, sharing the results of these experiments and promoting further research and development in this subject area can contribute to the advancement of the field and drive innovation in content delivery networks beyond today's technical achievements.

In all experiments, the CDCA solution is compared against a *legacy* network, i.e., a traditional Internet environment where the content is delivered directly from the content server to the user.

The main objective of the experiment is to evaluate the effectiveness of the users, considering the network provider and the content provider resources. To this extent, the first experiment aims to analyze how long a set of users would wait to retrieve arbitrary contents with different chunk sizes from an external server. The second experiment aims to verify how many data packets and bytes are exchanged within the network provider's infrastructure when requests for contents with distinct sizes are performed by several users. Finally, the third experiment checks the throughput at the content provider's server at different hit rates and Cache storage capacities when requests for content with distinct sizes are performed by many users.

### A. Experimental Environment Evaluation

The evaluation of the prototype using an emulation methodology provides a controlled and reproducible environment to assess the performance and behavior of the CDCA architecture. Mininet, a virtualized network platform, was chosen as the basis for the evaluation, offering the ability to create interconnected virtual devices such as hosts, switches, and controllers [30].

The evaluation scenario of the topology experiments was implemented within a c3.2xlarge Amazon EC2 VM, which provided sufficient resources including 8 virtual CPUs, 15GB of RAM, and 2 x 80GB of SSD storage. The virtualized devices in Mininet communicated with each other via virtual interfaces, enabling the execution of real protocol stacks in a virtual network.

The network topology used in the experiment is composed of one content server, one SDN Controller and six islands with three users each as shown in Fig. 3. The network driver and switching delay considered in Mininet environment are not shown. The latency stated in the figure is only the fiber propagation delay.

To control the traffic flow in the network, an OpenFlow Controller was employed. The Floodlight OpenFlow Controller was selected for its simplicity and development flexibility, which facilitated the implementation and management of the network environment [31]. The evaluation took into account the latency of a 1 Gbps Ethernet board driver (100 µs) and the switching latency in the Linux Open vSwitch. These latency values were set to be greater than those typically found in real network infrastructures to ensure the worst case scenario for evaluation purposes of the results.

The flexibility of Mininet allowed configuring parameters such as link bandwidth and delaying strategies, enabling the emulation of various network conditions and scenarios similar to production networks. This flexibility enhanced the accuracy and applicability of the evaluation results.

It is worth mentioning that the evaluation utilized OpenFlow version 1.0, as it was deemed sufficient for assessing the CDCA architecture. Subsequent versions of OpenFlow did not offer any new features or fields that would significantly impact the evaluation of the proposal.

By conducting the evaluation in this controlled environment, the researchers were able to gather data on the performance, scalability, and feasibility of the prototype. These insights help validate the effectiveness of the CDCA architecture and provide valuable information for further refinement and improvement. It has allowed for a comprehensive assessment of the CDCA architecture's capabilities in a realistic network setting.
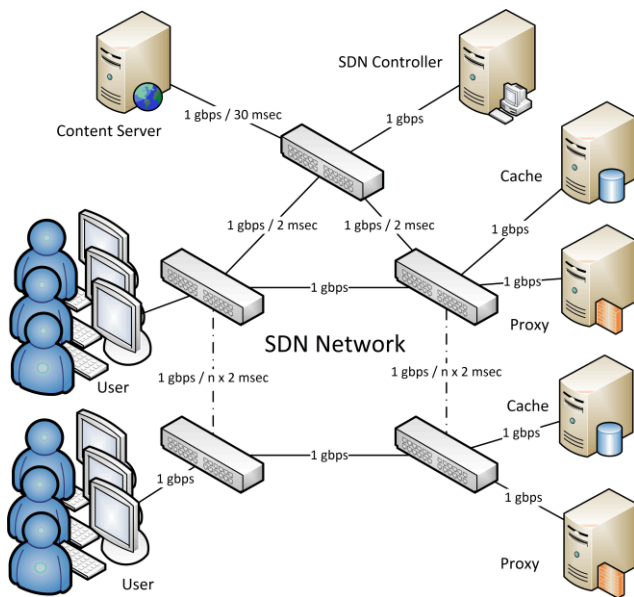
Fig. 3.    Evaluation topology of the experiment.

The experiment involved the initiation of multiple applications running over HTTP, encompassing a variety of content types ranging from plain text websites to multimedia video streams. The content response chunk sizes were varied in the range of 10 to 3200 kilobytes.

The methodology employed in the experiment drew inspiration from the work of Augustin et al. [32], who extensively analysed the bandwidth usage of Web 2.0 applications. By adopting a similar approach, the experiment aimed to evaluate the CDCA architecture's ability to handle a diverse range of applications and their associated bandwidth requirements. This experimental method was selected because it demonstrated success in addressing a wide spectrum of applications, including email and on-demand video streams. This approach also permitted gathering meaningful statistics and insights into the performance and efficiency of the CDCA architecture in handling different types of content and application scenarios. It also allowed conducting experiments with various content response chunk sizes and a diverse set of applications to assess the scalability, efficiency, and effectiveness of the CDCA architecture in accommodating different bandwidth demands and traffic patterns as well as providing valuable insights into its performance and potential benefits in practical deployment scenarios.

In the experiment, each user was implemented in Java using Apache's HTTP Client library to perform HTTP requests. Each user was single-threaded, and all users concurrently sent their requests.

To simulate realistic user behaviour, the Cache hit rate was set at 70%, meaning that 70% of the requests made by the users were expected to be found in the Cache and result in Cache hits. The CDN's Cache hit rate is variable and depends on the content and user profile. The literature typically regard CDN's hit rate estimate to be in the range from 60% to 90%, so an intermediate value was used. As we used emulation, the chunks were randomly generated and the client's hit rate was

set to 70%.

To optimize network resource utilization, each client used HTTP pipelining, which allows multiple requests to be sent over a single TCP connection without waiting for individual responses. This approach maximizes the use of network capacity by reducing the overhead of opening and closing TCP connections for each request. Each client was configured to have a maximum of 10 pipelined requests without responses, meaning that a client could have several pending requests in transit simultaneously, even though each client was single-threaded.

The perceived delay experienced by users was measured as a roundtrip time, starting from the moment a user sent an HTTP request until the corresponding response was received by the same user. This metric captured the overall time required for a user to receive a response and reflected the user's perceived delay in accessing the requested content.

To gather statistics on bytes and data packets, the OpenFlow Controller was utilized. After each experiment round, the OpenFlow Controller obtained the counter values for each port of the OpenFlow switches through StatsRequest messages [33]. This allowed collection of information on the amount of data transmitted and the number of packets exchanged within the network under realistic conditions. This approach provided insights into the system's ability to handle concurrent user requests, optimize network resources, and deliver content with reduced perceived delay.

In the first experiment, caches with a capacity of 1GB were used. This means that each Cache instance had the ability to store up to 1GB of content. The experiment aimed to evaluate the system's performance and effectiveness with this limited Cache capacity.

The second experiment involved two Cache instances, each with a capacity of 1GB. This setup allowed for a total Cache capacity of 2GB. By increasing the number of Cache instances, the system aimed to assess the impact of distributed caching on performance and content availability.

In the third experiment, Cache capacities varied from 2GB to 6GB. This range of capacities allowed the researchers to investigate the scalability and performance of the system as the Cache capacity increased. The experiment aimed to understand how increasing Cache capacity influenced Cache hit rates, perceived delay, and overall system efficiency.

In all three experiments, the caches were configured to use the Least Frequently Used (LFU) eviction policy. LFU is a Cache replacement policy that selects the least frequently used content for eviction when the Cache reaches its capacity limit. This policy is based on the assumption that content popularity is a significant factor in Cache usage, and frequently accessed content is more likely to be accessed again in the future.

Additionally, the caches in these experiments used an in-memory approach, meaning that the content was stored in the Cache's memory rather than on disk. This allowed for faster access times but limited the overall storage capacity compared to using disk-based storage.

The decision to use an LFU eviction policy and an in-

memory approach was based on previous research by Famaey et al. [34], which highlighted the effectiveness of popularity-based Cache replacement strategies for Video-on-Demand (VoD) services. Adopting LFU and an in-memory approach, allowed them to align the experiments with existing literature for comparison purposes and leverage the benefits of these strategies in their system.

### B. Experimental Results

In the first experiment, the user's average delay when requesting content from a server was evaluated. Each experiment was executed 10 times with different chunk sizes and hit rate of 70%, showing overall results of an average of 95% confidence interval as shown in Fig. 4. It demonstrates the effectiveness of the CDCA architecture in improving the user's delay perception.

The graph illustrates that the CDCA architecture led to a significant improvement in the user's delay, regardless of the content's size. On average, the delay was reduced by nearly 75% compared to traditional approaches. This improvement indicates that the CDCA architecture effectively optimizes content delivery and reduces the perceived delay from the user's perspective.

Furthermore, the result for 3200 kilobytes of contents showed an even higher improvement of almost 80%. This suggests that the CDCA solution not only enhances the user's delay but also reduces network traffic. By utilizing caching and efficient content delivery mechanisms, the CDCA architecture minimizes the need for repeated content requests, leading to reduced network congestion and improved overall performance.

These findings support the effectiveness of the CDCA architecture in improving user experience by reducing delay and optimizing content delivery, irrespective of the content's size.
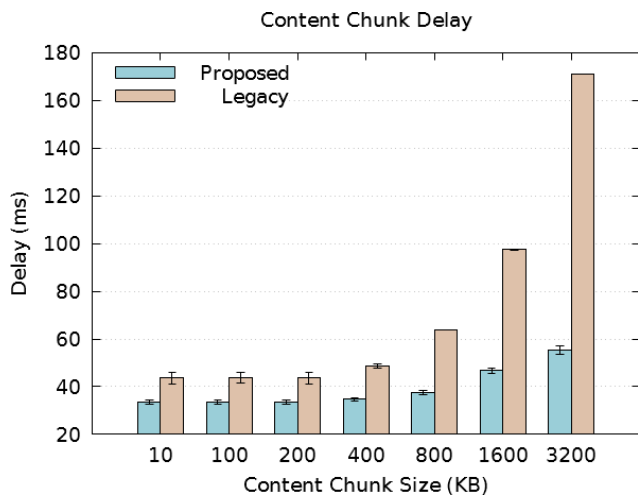


Fig. 4. User's observed delay with responses with different chunk sizes.

Fig. 5 displays the number of bytes transferred after the execution of the second experiment of the sum total of the number of bytes transferred through all switches at each network interface within the network topology. It compares the CDCA solution against traditional approaches. Both

values, for all content sizes, show a reduction in the number of bytes transferred when using the CDCA solution. This reduction can be attributed to the architecture's ability to deliver content closer to the users through caching. By caching content in proximity to the users, the need to transfer the same content repeatedly over the network is minimized. This result in a more efficient utilization of network resources and a reduction in the overall data transferred.
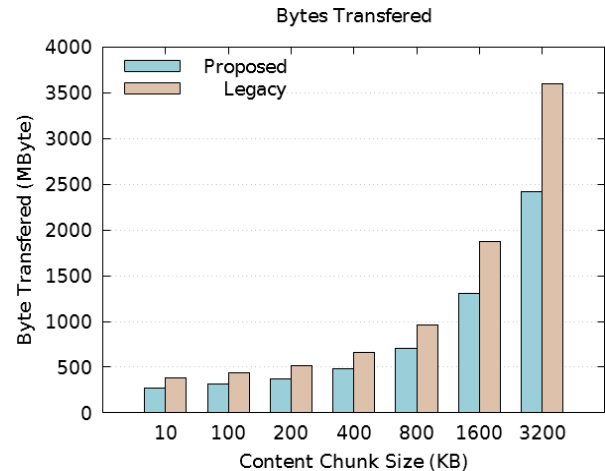


Fig. 5. Sum total of the number of bytes transferred through all switches.

The results show that the CDCA architecture effectively reduces the amount of data transferred, leading to more efficient network resource utilization and improved Quality of Experience (QoE) for users by reducing delay, as observed in the previous experiment, but also optimizes the use of network resources. The results highlight the positive impact of the CDCA architecture by minimizing data transfer and efficiently delivering content, the CDCA solution helps networks become more effective, ultimately reducing operational costs associated with bandwidth usage.

Fig. 6 and Fig. 7 show the results of the third experiment respectively.

From Fig. 6 it can be observed that operating with 2 caches storing 1GB of data the Cache hit rates increases and the throughput at the server decreases. This trend indicates that the CDCA architecture effectively reduces the number of requests which reaches the destination server as the Cache hit rate increases. This reduction in server requests is independent of the chunk size of the content. The results demonstrate that the caching mechanism of the CDCA architecture successfully offloads traffic from the server, improving its throughput.

Fig. 7 focuses on the influence of Cache capacity on server throughput at different Cache hit rates with response sizes of 3200 kilobytes. The graph shows that Cache capacity plays a significant role in the server's throughput, particularly at higher Cache hit rates. For example, at a hit rate of 40%, there is a noticeable difference of around 30 Mb/sec in server throughput when the Cache capacity increases by just 4GB. This difference becomes even more significant, reaching 100 Mb/sec, as the hit rates increase to 80%. These findings highlight the importance of Cache capacity in effectively reducing the load on the server and improving its throughput.
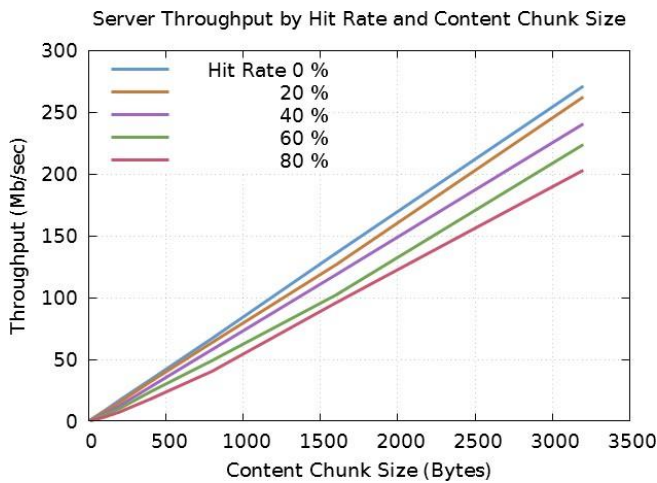
Fig. 6.    Server throughput at different Cache hit rates and response sizes.

With a larger Cache capacity, more content can be stored and served directly from the Cache, resulting in a reduced burden on the server. As a result, the CDCA architecture demonstrates its ability to alleviate the server's load and improve its performance, especially when higher Cache hit rates are achieved. The CDCA architecture successfully compels caching to offload traffic from the server and optimize its performance, leading to more efficient content delivery and enhanced network scalability.
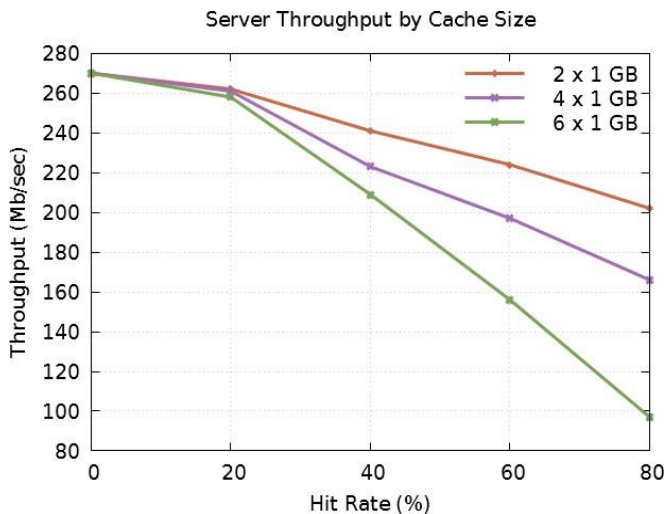


Fig. 7.    Server throughput with different Cache hit rates and capacities.

The consistent improvement patterns observed in both users' QoE metrics and network metrics, regardless of the content size, are indeed interesting findings. The CDCA solution, by caching content near users at high speeds, effectively reduces transmission time and improves overall performance, regardless of the size of the content being delivered.

This result suggests that the CDCA architecture efficiently utilizes caching mechanisms to deliver content to users, irrespective of the content's size. The proximity of the cached content to the users, combined with the optimized delivery process, minimizes the impact of content size on transmission time. Consequently, users experience similar levels of

improvement in QoE metrics, such as reduced delay and improved perceived performance, regardless of whether they are accessing small or large content.

Furthermore, improvements were also observed regarding server throughput and data transfer, reinforcing the effectiveness and validation of the CDCA architectural solution. By offloading traffic from the server and optimizing content delivery through caching, the architecture efficiently utilizes network resources, leading to reduced server load, decreased transferred bytes, and improved overall network operational efficiency while optimizing network performance and resource utilization.

*C.  Discussion of the Results*

In all three experiments, we can notice that the CDCA architecture has been effective in reducing the user's perceived delay, reducing the network data transfer, and reducing the network traffic at the content provider's server. The improvement on the user's QoE is intrinsically connected to the network data transfer reduction since fewer network segments need to be traversed in order to serve the content requests. As a result, if several requests are being handled by the Cache nodes spread over the network, then fewer requests need to be forwarded to the external content server, reducing the amount of data exchanged.

Fig. 7 provides valuable insights into the impact of Cache capacity on the system's performance. As the Cache capacity increases, the hit rate improves, resulting in a higher proportion of content being served from the Cache instead of the content server. This reduces the load on the server and improves overall throughput. Conversely, when the Cache capacity is low, frequent evictions occur, leading to more requests being forwarded to the content server. This not only increases the load on the server but also decreases the overall throughput, as observed in the results.

The findings suggest that the Cache capacity should be carefully considered during system deployment. Insufficient Cache capacity may result in higher eviction rates and increased dependence on the content server, ultimately affecting user experience and server performance. It is important to allocate an appropriate amount of Cache storage to accommodate the expected workload and ensure efficient content caching.

Furthermore, implementing a policy that selectively caches specific types of content, such as popular videos or audio, can optimize Cache utilization and prevent waste of resources. By focusing caching efforts on high-demand content, the Cache capacity can be effectively utilized to serve the most frequently requested content, enhancing overall performance and reducing the strain on the system.

These insights highlight the importance of careful Cache capacity planning and policy management in real-world deployments. By considering the workload characteristics, content popularity, and resource constraints, ISPs can design caching solutions that maximize the benefits of caching while efficiently utilizing Cache resources.

As depicted in Fig. 4 and Fig. 7, bigger content chunk

sizes and Cache storage leads to better results, indicating that large caches improve the system's performance. Nowadays, storage capacity is not a considerable problem since the ever-increasing capacity and decreasing prices of RAM and Flash memory provide affordable storage for huge capacity data (or files) resulting in superior overall system performance. And also, the system performance could be influenced by the Cache eviction policy used.

An initial approach for the ontology taxonomy utilizes four categories: (1) Content Type, (2) Content Identification, (3) Content Location, and (4) Content Chunk.

Content Type considers the content media type. There are two main categories of multimedia: time-sensitive media, e.g., video and audio, and non-time-sensitive media, e.g., documents and software. In the CDCA architecture, the time-sensitive content has to be treated in a different way in order to maintain the seamless delivery rate and guarantee the user real-time QoE. The video and audio parameters, i.e., resolution and CODEC, are used to quantify the required media rate in order to set the network provision once the end-user file is selected, preferably through the ontology search and found mechanism.

Content Identification is used to identify the content name, version, date and hash. This information is important for checking the content version to ensure that the most updated content version is delivered to the end user.

Finally, the use of multiple SDN controllers, proxies and caches, provides scalability by growing infrastructure horizontally. The Proxy and Cache implementation using a stateless *microservice* framework helps to meet all the scalability requirements. However, further studies will be necessary to determine any limitations in a large-scale deployment.

## VI. Open Research Issues, Challenges and Future R&D Directions

The CDCA architecture provides a transparent Cache system to improve the delivery of content objects inside an ISP infrastructure. Although outside the scope of this paper, there are still some open research issues that need to be considered before the CDCA system could be safely and practically deployed.

### A. Ontology Issues

The engine should offer the end-user the ability to find any content in a topic-specific manner, within a very short response time. In a real-life service production environment, it is possible for the network provider to host millions of content objects. To find topic-specific content with the correct version and date, it is necessary to organize the content index in an effective and efficient way, which should be approached through the use of some kind of dynamically updating knowledge-based ontology and deep machine learning techniques [35].

Several works have investigated the theory and practice of the semantic web and CDCA ontologies to organize the content classification [36]. However, most of these proposals focused on classifying the content to help the end-user find specific information, e.g., sport, business, travel, and so on. Nevertheless, in the CDCA solution, this kind of classification alone is not very useful because, for resourceful Cache management, it is not relevant whether the video is about sport or about travel, because the resolution, transmission rate and content chunk size are far more critical and significant for the optimization, sustainability and scalability. This does not mean that the content sought by the end-user is not important, but the selected optimum delivery of cached parts is the main consideration. The twin objectives of optimal seeking and delivery are crucial in formulating ontology.

Content-Location is important for finding the best geographic content distribution location point in order to improve the content QoE and the load balancing criteria during transmission.

The Content Chunk defines how the content chunk is divided and organized to improve the overall delivery and system performance. The content chunk is an atomic particle and it is the main element in the design of the CDCA architecture. The definition of its length is important to satisfy optimum delivery and system performance.

In a content-based network, the same content may have different names due to various reasons such as alternate naming strategies, load balancing, content distribution strategies, or user location-based routing. This can result in duplicate copies of the same content being stored in caches, leading to wastage of memory and storage resources.

To address this issue and avoid unnecessary hosting and caching of duplicate content, a hash mechanism can be employed. By calculating a hash value based on the content's data, such as using hash functions like MD5 or SHA-1, it becomes possible to determine whether multiple requests refer to identical content or not. The hash value serves as a unique identifier for the content, regardless of its name or location.

When a request is received, the system can calculate the hash value of the requested content and compare it with the existing Cache entries. If a matching hash value is found, it indicates that the content is already cached, and there is no need to store another copy. Instead, the existing cached copy can be retrieved and served to the requesting user.

By using a hash mechanism, the CDCA architecture can effectively identify and eliminate duplicate copies of content, thereby optimizing memory and storage resources in caches. It ensures that only one copy of the content is stored, regardless of the different names or variations associated with it due to load balancing or other factors. This approach helps in reducing storage overhead and improving the overall efficiency of the content delivery system.

### B. Optimization Issues

Although the CDCA architecture shows improvements in the response time of content requests and in the reduction of traffic from an external content provider, many aspects can be improved, as discussed in Section IV-C. We also envisage that it is possible to improve the content inspection algorithm to optimize searching and the application of a load-balancing mechanism. Although the system seems to

be scalable, further studies are necessary to determine any limitations in a large-scale system.

As noted earlier, the CDCA architecture utilized OpenFlow 1.0 because more recent versions do not offer any new field to improve the CDCA system. However, if a future version of the OpenFlow protocol implements matches in the HTTP Content-Type field, it will be able to forward certain specific MIME requests, for example, "video/mp4", direct to the Cache, avoiding the need for a Proxy. Even so, the content lookup should be done by the OpenFlow Controller instead of the Proxy. The lookup inside the switch diverges from the OpenFlow philosophy to maintain simplicity.

The issues mentioned in Section IV-C can be resolved by the configurable architecture. The configurable software approach means that the network administrator can deploy new VMs or adjust VM configuration, i.e., allocate memory and disk capacity when needed. This function can be accomplished by a cloud management and orchestration system. The CDCA prototype provides an open API that offers the capacity to change the eviction algorithm *on-the-fly*. The evaluation utilized the Least Frequently Used (LFU) eviction algorithm over RAM memory, as described in Section IV-D. In future research work it will compare the system behavior using various cache policies.

A critical issue, that should be investigated in the future, is the popularity prediction of User Generated Content (UGC). This is a valuable tool for content providers and advertisers. As the cached content is delivered inside the own ISP, the content provider could not get access to the user's profile. An interesting approach is proposed by Figueiredo et al [37].

It tackles the popularity prediction trend of a UGC object as early as possible to infer the user behavior. The results obtained by using YouTube datasets show an improvement of 38% in classification effectiveness, compared to the baseline approaches. Using this approach, the ISP can collect the user's information and notify the content provider.

### C. Security Issues

The CDCA system deployment within an ISP opens an opportunity with varying degrees of risk for external and internal security attacks of various kinds. It is possible that the CDCA critical infrastructure is susceptible to Distributed Denial of Service (DDoS) attacks affecting server provision and slowing down (or completely shutting down) the service, thereby frustrating the end user [38]. The distributed and open structure of a Cache system and its associated services can make it an attractive target for potential cyber-attacks. As with any system connected to the Internet, it is important to consider security measures to protect against intruders and mitigate the risks associated with cyber-attacks. These intruders can masquerade and manipulate various types of multimedia content, and therefore a supporting set of safety measures and security mechanisms and services would be needed to prevent intrusions and breaches. This would require a versatile, collaborative Intrusion Detection and Prevention System (IDPS) which must be flexible enough to guarantee smooth optimized streaming throughput flows with near-zero

(minimum) glitches.

Given the openness, and transparent nature of the mix-mode multimedia content delivery caching SDN architecture, traditional IDPS mechanisms would be fundamentally inefficient and ineffective [39]. In particular, it would be extremely difficult to detect intrusions in transparent multimedia content, hence preventing subsequent intrusions without employing a smart IDPS. It must involve advanced machine learning and computational intelligence techniques and the use of the five fundamental principles of autonomic self-management computing, knowledge base and ontology, risk management, fuzzy theory, and advanced artificial intelligence techniques [40] to leverage and satisfy the detection and prevention security capabilities of a Cache system. By incorporating these advanced techniques and concepts, the Cache system can enhance its ability to detect and prevent cyber-attacks, improve threat response mechanisms, and optimize overall security operations [41] [42]. However, it's important to consider the specific requirements and constraints of the Cache system via proper risk assessment and adapt these techniques accordingly to achieve effective and efficient operational and security outcomes.

HTTP/2 includes encryption as an optional facility. It is not mandatory because encryption can result in unnecessary jitter and distortion of the smooth viewing flow of videos. Many experts consider encryption unfeasible for ordinary large run-of-the-mill content delivery of videos. However, when and where cryptography is required, we also observe other major safety measures (security, privacy, trust, ID management, Digital Rights Management (DRM), digital *blockchaining* (virtual currencies), audit, digital forensic, non-copyediting, copyright infringement, permission to use, royalties, payments, etc.), and in particular issues related to the hiding of secret information using steganography will have to go beyond HTTP/2 specification. The complexities of these sets of safety measures are best accommodated by a comprehensive ontology.

### D. Copyright Infringement and Payment Issues

Another issue of importance and concern is that the CDCA architecture considers all content to be public without any restriction to distribution, which, however, makes the CDCA architecture unsuitable to deliver protected and paid content, such as required by some VoDs. Another example would be the rights of the content owner or their agent to be paid for documentaries, films, or music. Such content should typically be encrypted and the VoD provider can provide a temporary digital security key to the subscriber to decrypt the content for a certain period of time based on a payment scheme and without allowing copying of the content for further illegal distribution. This can be potentially achieved by activating the signature timeout period in conjunction with monitoring if the user attempts to copy the content. After this expiry period, the key is invariably disallowed, requiring the subscriber to renew the key to access the content. Implementing these security and protection measures requires careful consideration of technical, legal, and business aspects. It involves collaboration between content providers, payment service providers, DRM vendors, and security experts to

design and deploy a comprehensive and effective solution. This suggested scenario requires intensive research to fully define and design a secure payment mechanism that also curtails illegal copying, as well as verify and validate the mechanism for business deployment.

## VII. Conclusion and Future Work

This research has described a content-based transparent caching architecture in SDN. It provides a highly available, reliable and scalable caching of named content on SDN-based ISP networks, independent of specific underlying applications and middleware protocols. The research has also demonstrated that the caching mechanisms are driven by business policy needs and can be deployed in any networks, using the NFV approach and the microservice-based framework architecture. One notable aspect of the CDCA architecture is its support for the HTTP protocol, which remains the primary protocol for content delivery over the Internet. Rather than replacing HTTP, the system complements it by introducing transparent caching mechanisms that enhance content delivery and improve QoE for users.

The experimental evaluation conducted in the research demonstrates the effectiveness of the CDCA system. It shows improvements in user QoE and various QoS network metrics related to delivery times and scalability. This validation reinforces the benefits of the architecture and its potential to enhance content delivery in real-world network scenarios.

The CDCA architectural system has some important outstanding issues that should be addressed in future research and development work. At present, there is no effort by content providers and related industry players to develop a standardized naming scheme for content, which is crucial for efficient and optimum search and delivery of content, as well as for avoiding duplication of names and content hosted all throughout the provider network. In addition, the new naming scheme should avoid the same content with different names being downloaded multiple times. It is important for content providers and industry players to recognize the significance of a standardized naming scheme and work toward its development and adoption.

In future research work, the intent is to address many of the issues mentioned in the previous section. In addition, further research work is planned to perform analyses of several other video content providers, other than YouTube, to adapt the CDCA solution, if necessary. Another critical issue, which will be investigated, is the *popularity prediction* of UGC, which is a valuable tool for content providers and advertisers for revenue generation.

Finally, another area for future work involves system security. In the CDCA architecture, the ISP acts as a content provider, and it could suffer external and internal DDoS attacks, affecting servers slowing/shutting down the service and frustrating users. Further, multimedia content could be manipulated for illegal cybercrime activities, which should be avoided through the proper implementation of safety measures. Traditional IDPS is largely inefficient for the CDCA environment due to its architecture and virtualization. A new IDPS paradigm should be designed to achieve a high level of security health in the service provider network. In addition, we have highlighted issues related to secure payment and royalty awarding schemes for content that is primarily declared as public but that requires payment to intellectual property owners or their agents. Property rights issues also involve various safety measures. These system security challenges require creative solutions and therefore offer opportunities for further research.

## References

[1] J. S. Turner and D. E. Taylor, "Diversifying the Internet," in *IEEE Global Telecommunications Conference (GLOBECOM 2005)*, vol. 2, IEEE. Institute of Electrical & Electronics Engineers (IEEE), Dec 2005, pp. 760–766.

[2] Cisco, "Cisco visual networking index: Forecast and methodology, 2016-2021 white paper," [Online]. Available: http://www.cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/complete-white-paper-c11-481360.html

[3] J. F. Gantz, D. Reinsel, C. Chute, W. Schlichting, J. Mcarthur, S. Minton, I. Xheneti, A. Toncheva, and A. Manfrediz, "The expanding digital universe: A forecast of worldwide information growth through," *Information and Data 2007*, pp. 1–21, 2010.

[4] B. Ahlgren, C. Dannewitz, C. Imbrenda, D. Kutscher, and B. Ohlman, "A survey of information-centric networking," *IEEE Communications Magazine*, vol. 50, no. 7, pp. 26–36, July 2012.

[5] L. Veltri, G. Morabito, S. Salsano, N. Blefari-Melazzi, and A. Detti, "Supporting information-centric functionality in software defined networks," in *IEEE International Conference on Communications (ICC2012)*. IEEE, 2012, pp. 6645–6650.

[6] A. Ooka, S. Ata, T. Koide, H. Shimonishi, and M. Murata, "Openflow-based content-centric networking architecture and router implementation," in *Future Network and Mobile Summit (FutureNetworkSummit 2013)*. IEEE, July 2013, pp. 1–10.

[7] X. N. Nguyen, D. Saucez, and T. Turletti, "Efficient caching in content-centric networks using openflow," in *Proceedings IEEE INFOCOM 2013*, April 2013, pp. 1–2.

[8] D. Syrivelis, G. Parisis, D. Trossen, P. Flegkas, V. Sourlas, T. Korakis, and L. Tassiulas, "Pursuing a software defined information-centric network," in *European Workshop on Software Defined Networking (EWSDN2012)*. IEEE, Oct 2012, pp. 103–108.

[9] N. McKeown, T. Anderson, H. Balakrishnan, G. Parulkar, L. Peterson, J. Rexford, S. Shenker, and J. Turner, "OpenFlow: enabling innovation in campus networks," *ACM SIGCOMM Computer Communication Review*, vol. 38, no. 2, pp. 69–74, Mar 2008.

[10] M. Ciosi *et al.*, "Network functions virtualisation: an introduction, benefits, enablers, challenges and call for action, introductory white paper," in *"SDN and OpenFlow World Congress"*, 2012, pp. 152–160.

[11] A. Chanda and C. Westphal, "A content management layer for software-defined information centric networks," in *Proceedings of the 3rd ACM SIGCOMM workshop on Information-centric networking*, ACM. ACM, 2013, pp. 47–48.

[12] P. Georgopoulos, M. Broadbent, B. Plattner, and N. Race, "Cache as a service: leveraging sdn to efficiently and transparently support video-on-demand on the last mile," in *23rd International Conference on Computer Communication and Networks (ICCCN2014)*. IEEE, Aug 2014, pp. 1–9.

[13] A. F. Trajano and M. P. Fernandez, "Two-phase load balancing of in-memory key-value storages using network functions virtualization

(nfv)," *Journal of Network and Computer Applications*, vol. 69, pp. 1–13, Jul 2016.

[14] D. Levin, A. Wundsam, B. Heller, N. Handigol, and A. Feldmann, "Logically centralized?: State distribution trade-offs in software defined networks," in *Proceedings of the First Workshop on Hot Topics in Software Defined Networks*, ser. HotSDN '12, ACM. New York, NY, USA: ACM, 2012, pp. 1–6.

[15] M. P. Fernandez, "Comparing openflow Controller paradigms scalability: Reactive and proactive," in *IEEE 27th International Conference on Advanced Information Networking and Applications (AINA2013)*. IEEE, March 2013, pp. 1009–1016.

[16] F. Sultan, K. Srinivasan, D. Iyer, and L. Iftode, "Migratory tcp: Connection migration for service continuity in the internet," in *Distributed Computing Systems, 2002. Proceedings. 22nd International Conference on*. IEEE, 2002, pp. 469–470.

[17] S. Koulouzis, A. S. Belloum, M. T. Bubak, Z. Zhao, M. Živković, and C. T. de Laat, "SDN-aware federation of distributed data," *Future Generation Computer Systems*, vol. 56, pp. 64–76, March 2016.

[18] M. Belshe, R. Peon, and M. Thomson, "Hypertext Transfer Protocol Version 2 (HTTP/2)," RFC 7540 (Proposed Standard), Internet Engineering Task Force, May 2015.

[19] S. Wei and V. Swaminathan, "Low latency live video streaming over http 2.0," in *Proceedings of Network and Operating System Support on Digital Audio and Video Workshop*, ser. NOSSDAV '14. New York, NY, USA: ACM, 2014, pp. 37:37–37:42.

[20] S. Alcock and R. Nelson, "Application flow control in YouTube video streams," *ACM SIGCOMM Computer Communication Review*, vol. 41, no. 2, p. 24, apr 2011.

[21] T. Hoßfeld, R. Schatz, and U. R. Krieger, "QoE of Youtube video streaming for current internet transport protocols," in *Measurement, Modelling, and Evaluation of Computing Systems and Dependability and Fault Tolerance*. Bamberg, Germany: Springer International Publishing, 2014, pp. 136–150.

[22] V. K. Adhikari, S. Jain, and Z.-L. Zhang, "Where do you"tube"? Uncovering youtube server selection strategy," in *Proceedings of 20th International Conference on Computer Communications and Networks (ICCCN2011)*. IEEE, 2011, pp. 1–6.

[23] A. Balamash and M. Krunz, "An overview of web caching replacement algorithms," *IEEE Communications Surveys & Tutorials*, vol. 6, no. 2, pp. 44–56, 2004.

[24] J. Wang, "A survey of web caching schemes for the internet," *ACM SIGCOMM Computer Communication Review*, vol. 29, no. 5, pp. 36–46, 1999.

[25] S. Gao, Y. Zeng, H. Luo, and H. Zhang, "Scalable control plane for intra-domain communication in software defined information centric networking," *Future Generation Computer Systems*, vol. 56, pp. 110 – 120, March 2016.

[26] K. Phemius, M. Bouet, and J. Leguay, "Disco: Distributed multi-domain sdn controllers," in *IEEE Network Operations and Management Symposium (NOMS2014)*. IEEE, May 2014, pp. 1–4.

[27] A. Dixit, F. Hao, S. Mukherjee, T. Lakshman, and R. Kompella, "Towards an elastic distributed sdn Controller," *ACM SIGCOMM Computer Communication Review*, vol. 43, no. 4, pp. 7–12, 2013.

[28] P. Berde, M. Gerola, J. Hart, Y. Higuchi, M. Kobayashi, T. Koide, B. Lantz, B. O'Connor, P. Radoslavov, W. Snow *et al.*, "Onos: towards an open, distributed sdn os," in *Proceedings of the Third Workshop on Hot Topics in Software Defined Networking*, ser. HotSDN '14, ACM. New York, NY, USA: ACM, 2014, pp. 1–6.

[29] I. Stoica, R. Morris, D. Karger, M. F. Kaashoek, and H. Balakrishnan, "Chord: A scalable peer-to-peer lookup service for internet applications," *SIGCOMM Comput. Commun. Rev.*, vol. 31, no. 4, pp. 149–160, Aug. 2001.

[30] B. Lantz, B. Heller, and N. McKeown, "A network in a laptop: rapid prototyping for software-defined networks," in *Proceedings of the Ninth ACM SIGCOMM Workshop on Hot Topics in Networks*, ser. Hotnets '10. New York, NY, USA: ACM, 2010, pp. 19:1–19:6.

[31] D. Erickson, "Floodlight Java based OpenFlow Controller," [Online]. Available: http://floodlight.openflowhub.org/

[32] B. Augustin and A. Mellouk, "On Traffic Patterns of HTTP Applications," in *IEEE Global Telecommunications Conference (GLOBECOM 2011)*, Dec 2011, pp. 1–6.

[33] N. L. M. Van Adrichem, C. Doerr, and F. Kuipers, "Opennetmon: Network monitoring in OpenFlow Software-Defined Networks," in *IEEE Network Operations and Management Symposium (NOMS'2014)*. IEEE,May 2014, pp. 1–8.

[34] J. Famaey, F. Iterbeke, T. Wauters, and F. De Turck, "Towards a predictive Cache replacement strategy for multimedia content," *Journal of Network and Computer Applications*, vol. 36, no. 1, pp. 219–227, 2013.

[35] N. Talpur, S. J. Abdulkadir, H. Alhussian, M. H. Hasan, N. Aziz, A. Bamhdi. A comprehensive review of deep neuro-fuzzy system architectures and their optimization methods. Neural Comput & Applic 34, 1837–1875 (2022). https://doi.org/10.1007/s00521-021-06807-9.

[36] S. Dumais and H. Chen, "Hierarchical classification of web content," in *Proceedings of the 23rd annual international ACM SIGIR conference on Research and development in information retrieval*, ser. SIGIR '00, ACM. New York, NY, USA: ACM, 2000, pp. 256–263.

[37] F. Figueiredo, J. M. Almeida, M. A. Gonçalves, and F. Benevenuto, "TrendLearner: Early prediction of popularity trends of user generated content," *Information Sciences*, vol. 349-350, pp. 172–187, July 2016.

[38] Tiago Linhares, Ahmed Patel, Ana Luiza Barros and Marcial Fernandez. 2023. SDNTruth: Innovative DDoS Detection Scheme for Software-Defined Networks (SDN). Journal of Network and Systems Management, (2023) 31:55, (online) https://doi.org/10.1007/s10922-023-09741-4

[39] A. Patel, M. Taghavi, K. Bakhtiyari, and J. C. Júnior, "An intrusion detection and prevention system in cloud computing: A systematic review," *Journal of Network and Computer Applications*, vol. 36, no. 1, pp. 25–41, Jan 2013.

[40] N. Talpur, S. J. Abdulkadir, H. Alhussian, M. H. Hasan, N. Aziz, A. Bamhdi. "Deep Neuro-Fuzzy System application trends, challenges, and future perspectives: a systematic survey." Artificial Intelligence Review. 13:1-49. (2023). https://doi.org/10.1007/s10462-022-10188-3.

[41] A. Patel, H. Alhussian, J. M. Pedersen, B. Bounabat, J. C. Júnior, and S. Katsikas, "A nifty collaborative intrusion detection and prevention architecture for smart grid ecosystems," *Computers & Security*, vol. 64, pp. 92–109, January 2017

[42] A. M. Bamhdi. FLORA: Fuzzy Logic - Objective Risk Analysis for Intrusion Detection and Prevention IJCSNS International Journal of Computer Science and Network Security, VOL.23 No.5, pp.179-192 May 2023. https://doi.org/10.22937/IJCSNS.2023.23.5.20

[43] Leyva-Mayorga, Israel, et al. "Network-coded cooperation and multi-connectivity for massive content delivery." IEEE Access 8 (2020): pp 15656-15672.

[44] Cisco Annual Internet Report (2018–2023) White Paper. Available: https://www.cisco.com/c/en/us/solutions/collateral/executive-perspectives/annual-internet-report/white-paper-c11-741490.html

[45] Hong, Dohy, Danny De Vleeschauwer, and Francois Baccelli. "A chunk-based caching algorithm for streaming video." NET-COOP 2010-4th Workshop on Network Control and Optimization. 2010.

# An Improved Hybrid A* Algorithm of Path Planning for Hotel Service Robot

Xiaobing Cao[1], Yicen Xu[2], Yonghong Yao[3], Chenbo Zhi[4]

School of Control Technology, Wuxi Institute of Technology, Jiangsu Wuxi, 214121, China[1, 3]
School of Intelligent Equipment and Automotive Engineering, Wuxi Institute of Commerce, Jiangsu Wuxi, 214153, China[2]
Xi'an Research Institute of Huawei Technology Co, Ltd, Shaanxi Xi'an, 710075, China[4]

*Abstract*—**Due to the increasing demand for unmanned in the hotel industry in recent years, how to efficiently use hotel service robots to further improve the efficiency of the hotel industry has become a hot research issue. To solve the problems of lengthy path-finding time and poor route security in conventional service robots in complex environments, the current study provides an improved A\* path-finding algorithm for application in the hotel environment. Firstly, the conventional A\* algorithm is combined with bidirectional search and Jump Point Search (JSP) algorithm, which makes the search more effective. Secondly, the traditional A\* algorithm is combined with the security weight square matrix to make the path trajectory safer. A cubic spline interpolation is chosen to smoothen the transitions at the corners planned by the improved A\* algorithm. Simulation experiments were done on grid maps with 10\*10, 20\*20 and 50\*50 sizes. Compared with the conventional A\* algorithm, the search time were decreased by 67%, 77% and 95% respectively. The number of search nodes was decreased by 80%, 76% and 95%, respectively. Meanwhile the distance between the robot and the obstacles was increased. The results indicate that the improved A\* algorithm suggested in the present research can ensure the path trajectory safer while keeping the path search efficiency higher.**

*Keywords—Path planning; bidirectional A\* algorithm; JPS algorithm; security weight square matrix; cubic spline interpolation method*

## I. INTRODUCTION

Path planning is an important technology to ensure the hotel service robot can complete the corresponding tasks; the purpose is to plan a reasonable and safe route from the starting point to the target point without collision based on the corresponding task requirements [1]. For the hotel scene with high real-time requirements and a complex environment, it is necessary to design an algorithm to consider both real-time and security and increase the operation efficiency of the service robot. This research aims to investigate the A\* algorithm [2] for a fast and secure path planning problem.

Many scholars have done various investigations on the path planning of mobile robots. Regarding various search environment information, the planning is classified into global and local path planning. Among them, A\* algorithm [3], Dijkstra algorithm [4], RRT\* algorithm [5] are relatively common global path planning algorithms, while local path planning algorithms include dynamic window method, artificial potential field method and genetic algorithm [6], [7]. Although several researchers have researched this subject,

many deficiencies still exist. For example, in [8], a novel fusion algorithm of jump-A∗ algorithm and Dynamic Window Approach (DWA) was presented to satisfy global optimality and path smoothness performance requirements in robot path planning. However, the security of the planning path is unsatisfactory. To make robot movements safe in a realistic environment, Zhang et al. [9] considered node-to-obstacle distances in the A\* extension node and used the threat generation value to assess node cost. That algorithm guarantees the safety of the path, and its computation time is also increased. Some three-path smoothers have been designed by Song et al. [10] for optimizing the paths, but the algorithm's time complexity is sensitive to the scale of the node number. In [11], a Bi-directional Adaptive Probabilistic Method having a Triangular Segmented Interpolation was developed to increase the real-time performance of path search by an Adaptive-RRT approach and a Bi-directional scheme. However, there are still too many redundant nodes. We synthesize the solutions involved in the above literatures, and organize their methods, advantages and disadvantages in the Table I.

TABLE I. ADVANTAGES AND DISADVANTAGES OF EXISTING METHODS

| Method | Advantages (well considered) | Disadvantages (not fully considered) |
|---|---|---|
| fusion of jump-A\* algorithm and DWA | computation time and path smoothness | security |
| A∗ algorithm taking the safety cost into account | safety and smoothness | computation time |
| A∗ algorithm with three path smoothers | Path smoothness | computation time |
| Bi-directional adaptive probabilistic method | computation time and path smoothness | redundant nodes |

As shown in Table I, the related research work of other scholars on the path planning algorithm have been comprehensively studied and improved from the aspects of real-time, security and smoothness, and satisfactory results have been achieved. Thus, the research in this paper adopts a new improved way to achieve better performance of A\* algorithm in the hotel environment. To realize that the hotel service robot can travel in the globally optimal path and keep a safer distance from obstructions, this paper proposes a new solution. A global path planning algorithm combined with bidirectional search and Jump Point Search (JSP) algorithm, also combined with the security weight square matrix is suggested in the present study in terms of improved A\*.

The contributions of the improved hybrid algorithm recommended in the present research to the path planning

problem are as follows.1) The concept of bidirectional search [12] and JPS jump point search [13], [14] is used to promote the searching efficacy of the traditional A* algorithm. 2) The security weight square matrix with the idea of multi-neighborhood search [15], [16] is suggested as a new method for helping the robots prevent temporary obstacles in the global path. According to the requirements of different safety distances, that manner sets the corresponding neighbourhood matrix to complete the detection of obstacles, making the path trajectory safer. 3) Cubic spline interpolation is employed to improve the smoothness of the path [17], which is unsmooth at the corner.

The remaining of the paper is as follows. Section II first reviews the traditional A* algorithm, then discusses the bidirectional A* algorithm regarding Jump Point Search and presents a cubic spline interpolation method to smooth the turning of the path. Thirdly, it introduces the security weight square matrix. Finally, the steps of the improved hybrid A* algorithm proposed in the present article are summed. Section III represents the experimental results of the simulation. Section IV concludes the whole research in summary and provides future research directions.

## II. IMPROVED A* ALGORITHM

### A. Traditional A* algorithm

A* algorithm [18], [19] is a heuristic search algorithm relying on the cost function. It can be considered as the most efficient direct search method to solve the shortest path in static road networks, usually used in global planning grid map scenes. The algorithm can evaluate the cost value of nodes around the existent path and find the node with the lowest cost value as the next moving point, and so on, until the robot reaches the target point. The formula of the cost function is defined in Equation (1):

$$F(n) = G(n) + H(n) \qquad (1)$$

Where F(n) is the cost value of the current moving node, G (n) represents the cost value from the starting node to the current moving node, and H (n) represents the cost value from the current moving node to the target node.

### B. Real-Time Improvement of A* Algorithm

The traditional A* algorithm searches from the starting point to the target point, but its search effectiveness is not optimal. Hence, an improved A* algorithm is suggested by some scholars [20]–[23] that changes the one-way search of the primary algorithm to the bi-directional search. The improved A* algorithm searches from the starting point and the target point simultaneously, which greatly enhances the search effectiveness. The specific formula is as follows.

$$\begin{cases} F_1(n) = G_1(n) + H_1(n) \\ F_2(n) = G_2(n) + H_2(n) \end{cases} \quad (2)$$

Where $F_1(n)$ is the cost value from the starting point to the target point and $F_2(n)$ is the cost value from the target point to the starting point. When one party detects the checked node of the other party, the value of $F_1(n) + F_2(n)$ is the minimum and the search ends.

For the bidirectional search, it is easy to form a parallel search range while the obstacles exist between the starting and target points, increasing traversal nodes. Hence, this work mixes the JPS algorithm with the A* algorithm, greatly reducing traversal nodes by selecting corresponding hop points. OpenList1 and OpenList2 are established in this paper, respectively, representing the search from the starting point to the target point and vice versa. When searching the path, the two search directions are carried out alternately. The jump point is added to Openlist1 when searching in the forward direction. Then, the forward search is stopped and changed to the reverse direction. When searching in the reverse direction, the jump point is added to Openlist2, then stop the reverse direction search and start the forward direction search again. Carry out the forward and reverse search alternately until the same jump point is added to Openlist1 and Openlist2, which means the optimum path is found.

The improved A* algorithm can search a suitable path quickly, but a large turning point still exists at the corner. A relatively smooth turning is usually required for the specific complex hotel scenario. The present paper selects the cubic spline interpolation [24], [25] method to smoothen the turning trajectory in the improved A* algorithm. Its detailed definition is shown as follows.

For a piecewise function S(x), if $S(x) = S_i(x)$ is a cubic polynomial in every interval $[x_i, x_{i+1}]$ $(i = 0,1,2,3, \cdots, n-1)$ composed of n + 1 discrete points and $S(x_i) = y_i (i = 0,1,2,3, \cdots, n)$ is satisfied at each point, this function S(x) is a cubic spline interpolation function. Since S(x) is a second derivative and the second derivative is continuous in the continuous interval $[m, n]$, the S (x) curve can be understood as a smooth curve, so the path it fits at the corner is naturally smooth.
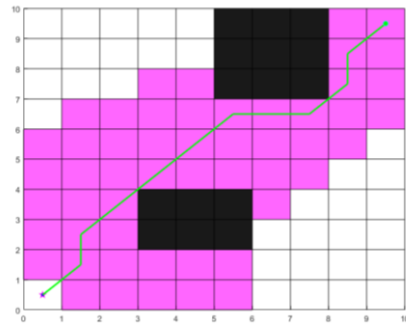


Fig. 1. Traditional A* algorithm.
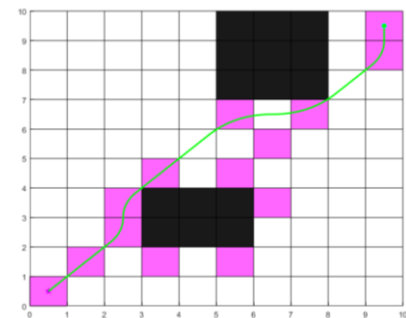


Fig. 2. A* algorithm integrated with JPS and bidirectional search.

Fig. 1 and Fig. 2 show the simulation experiments of the traditional A* algorithm and the A* algorithm integrating JPS and bidirectional search, where the black square shows the obstacle, the pink square represents the search node, and the green line refers to the planned path. The simulation experiments above demonstrate that the improved algorithm has fewer search nodes and better real-time performance. Although it smooths the turning of the path, a big risk of collision between the hotel service robot and obstacles still exists because of the close distance. Therefore, how to promote security is a crucial problem.

*C. Security Improvement of A* Algorithm*

In a traditional A* algorithm, the path planning situation shown in Fig. 3 usually occurs where the green S square denotes the starting point, the red G square denotes the target point, the black square denotes the obstacle, and the blue line denotes the planned path. However, it ignores the volume of the robot in practical application, which easily causes a false collision at the position marked X. This paper introduces the idea of a security weight square matrix for ensuring that the mobile robot can effectively keep a safe distance from obstacles, to increase the security of the algorithm.
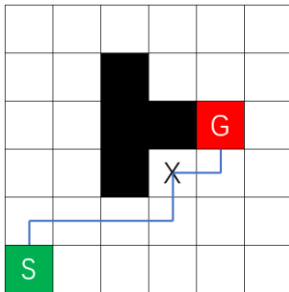


Fig. 3.    Path planned via A* algorithm before security improvement.
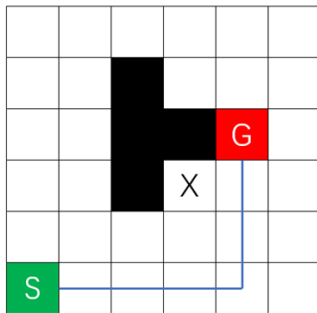


Fig. 4.    Path planned via A* algorithm with security improvement.

According to the multi-neighbourhood search idea, the present work designs a corresponding neighbourhood matrix to complete the detection of obstacles according to the requirements of different safety distances. Because the map environment type in this paper is a grid map, the minimum safe distance from obstacles is set as the distance of a grid, and the size of the corresponding neighbourhood matrix is 3*3, which is also known as the basic comparison matrix. Taking the basic comparison square matrix as an example, the central element of the square matrix is set as the current path node with a value of 0 and other position values are set to 1, which can be shown in the following matrix.

$$B = \begin{pmatrix} 1 & 1 & 1 \\ 1 & 0 & 1 \\ 1 & 1 & 1 \end{pmatrix} \quad (3)$$

In the process of path search, if an obstacle is detected within the range of the matrix, the element value of the corresponding position should be changed from 1 to 2 to generate a security weight square matrix, indicating that there is an obstacle. For example, for the path node X in Fig. 3, its security weight square matrix is.

$$X_B = \begin{pmatrix} 2 & 2 & 1 \\ 2 & 0 & 1 \\ 1 & 1 & 1 \end{pmatrix} \quad (4)$$

Set $d$ as the safety factor. If $d$ is larger, the degree of path safety is higher. If there exists 2 in the square matrix, set $d$ to 5 (the actual situation can be selected on its own), indicating obstacles near the current node. Otherwise, $d$ is 0. The detailed expression can be written as follows.

$$d = \begin{cases} 5 & \exists X_{B_{ij}} = 2 \\ 0 & \forall X_{B_{ij}} \neq 2 \end{cases} \quad (5)$$

The functional cost of the improved A* algorithm is shown in formula (6), where m is the number of 2 in the statistical basis comparison matrix, also known as the obstacle influence factor. The larger its value is, the more obstacles near the current node. As shown in Fig. 4, due to the increase in the cost value for the original path node, the path node is re-selected to keep the path away from obstacles.

$$f(n) = g(n) + h(n) + md \quad (6)$$

The matrix transformation can be based on the basic comparison matrix to set other safety distances. Using formula (8) with the transformation matrix A, the comparison matrix C of k*k (k is odd) with the central element value of 0 and the remaining elements value of 1 is obtained.

$$A = \begin{pmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ & \cdots & \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{pmatrix}_{k \times 3} \quad (7)$$

$$\begin{cases} C = \frac{1}{8} ABA^T \\ C_{\frac{k}{2}+1 \ \frac{k}{2}+1} = 0 \end{cases} \quad (8)$$

According to formula (4), the comparison square matrix C generates the security weight square matrix and the path node is re-selected. The flowchart of security improvement for the A* algorithm is shown in Fig. 5.
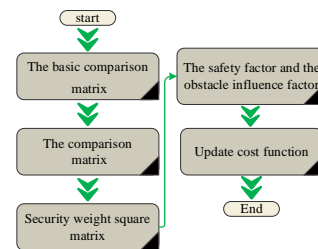


Fig. 5.    A* algorithm security improvement flow chart.

## D. *Improvement of Hybrid A* Algorithm*

To effectively promote the path planning algorithm in a specific service robot in the hotel environment, the present study mixes a bi-directional A* algorithm with a JPS algorithm to enhance its real-time performance. Simultaneously, it combines the idea of a security weight square matrix to enhance the algorithm's security. Finally, the cubic spline interpolation method is applied to smooth the improved A* algorithm at the path corner to construct the improved A* global path planning algorithm. The flow chart of the improved A* algorithm is represented in Fig. 6. The detailed steps include:

*1)* Create a grid map, initialize the corresponding parameters, starting point position and target point position, establish OpenList1 and OpenList2, select the first hop point and add it to OpenList1.

*2)* Set the safety distance. This paper uniformly sets the safety distance to facilitate comparison as 1 grid distance.

*3)* Compare the distance between the hop point to be selected and the obstacle, and add it to OpenList1 if it meets the conditions during the forward search.

*4)* Judge whether the jump point exists in OpenList2. If so, smooth the turning of the path. If not, stop the forward search and change to the reverse search.

*5)* Compare the distance between the jump point to be selected and the obstacle, and add it to OpenList2 if it meets the conditions during the reverse search.

*6)* Judge whether the jump point exists in OpenList1. If so, smooth the turning of the path. If not, stop the reverse search and change to the forward search.

*7)* Loop steps 3 to 6.

*8)* Output the optimal path.
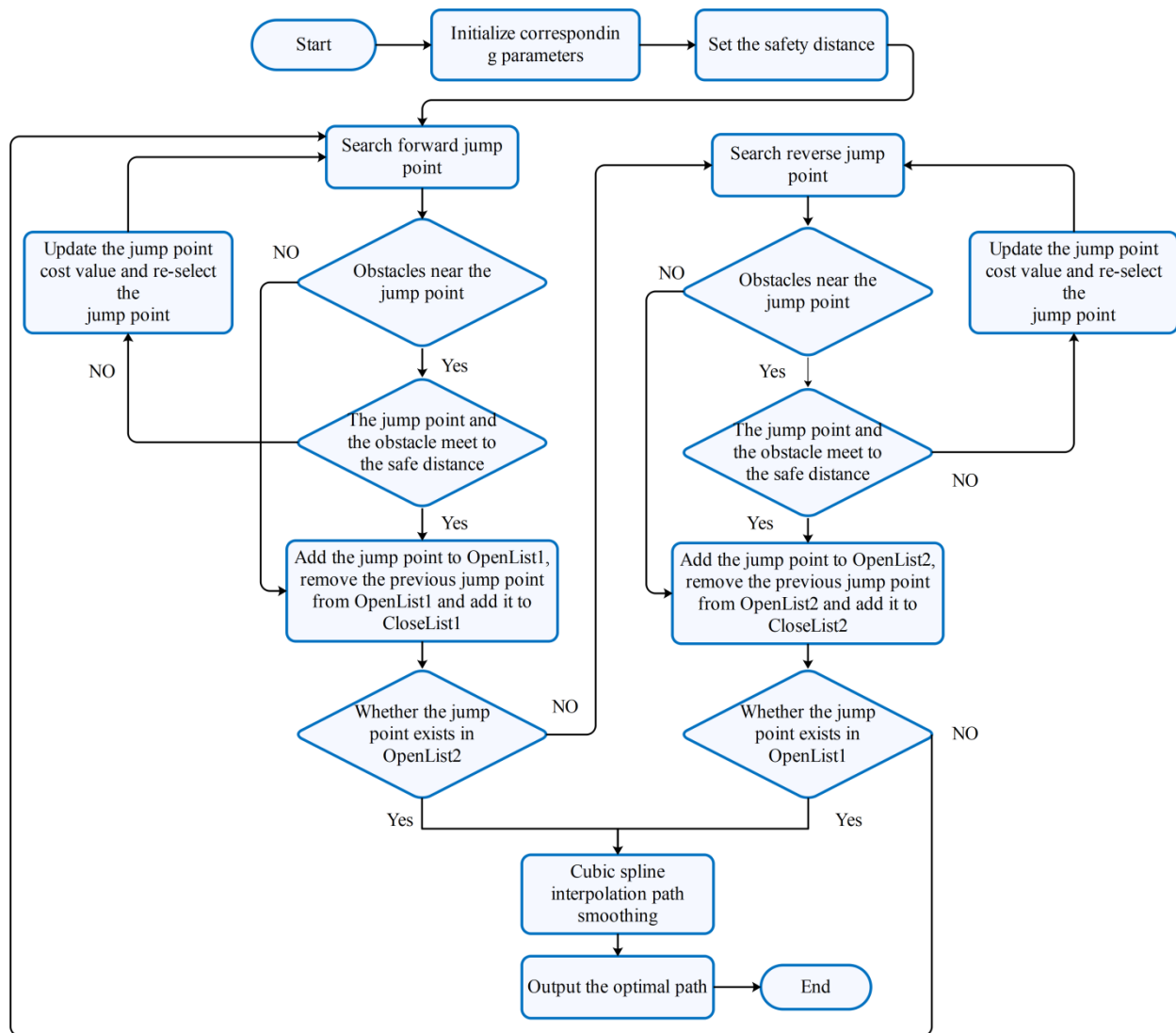


Fig. 6. Flow chart of improved A* algorithm.

## III. SIMULATION EXPERIMENTAL ANALYSIS

### A. Simulation Scenarios and Conditions

Simulation experiments are done in this part to validate the improved A* algorithm in mobile robots' authentic path-planning process. The computer parameters of the simulation environment are system Windows 10, CPU Intel Core i5 4210h, memory 8GB, compilation environment MATLAB 2016b. Since the research work of this paper comes from a real hotel robot project, we simulate three sets of grid map environments with different sizes and several sparse obstacles. These grid maps are associated with a real hotel scene and the sizes of them are 10 * 10, 20 * 20, 50 * 50 grids, respectively.

### B. Results and Discussion

The simulation results have been presented in Fig. 7 to 9, where the black square shows the obstacle, the pink square indicates the search node, and the green line refers to the planned path. The test of each group presents an analytical contrast between the results of these two methods based on the nodes and path length.

As shown in Fig. 7, the improved hybrid A* algorithm reduces the number of nodes from 61 to 12 compared with the traditional algorithm. In the middle size map as shown in Fig. 8, the improved hybrid A* algorithm reduces the number of nodes from 139 to 33, and in the large map as shown in Fig. 8, the number of nodes is reduced from 787 to 42. It can

be seen from the comparison of Fig. 7(a) and Fig. 7(b), the safe distance from the obstacle is increased about 1 grid and the path is smoother in the simulation results for the improved hybrid A* algorithm, and the same results can also be obtained from Fig. 8 and Fig. 9.

Total counts of nodes, path lengths and search time are further used to evaluate the improved algorithm's efficacy, as shown in Table II. It can be seen that compared with the traditional algorithm, the search time of the improved A* algorithm for 10 * 10, 20 * 20, 50 * 50 environmental raster maps are reduced from 0.082 s to 0.027 s, from 0.198 s to 0.046 s, and from 1.211 s to 0.065 s, respectively. Although the path length increased, the search time and the number of nodes have decreased. By comparing the results shown in Table I, it can also be seen that the improved A*algorithm has obvious priority regarding search time and node number with the expansion of the map area. Although the path planning length is relatively long, it can guarantee the safety of the path trajectory.

Consequently, from the previous analysis of the results, we can conclude that the improved A* algorithm suggested has fewer search nodes and less search time while keeping safe distance compared with traditional A* algorithm. It is proved that the algorithm presented in the paper enables the search for an optimum path under the condition of ensuring safety and shows good robustness and real-time performance.
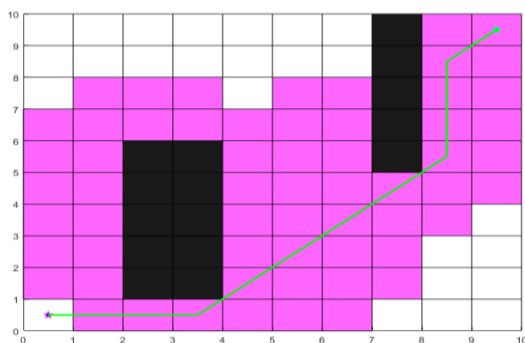


(a) Simulation results for the traditional A* algorithm
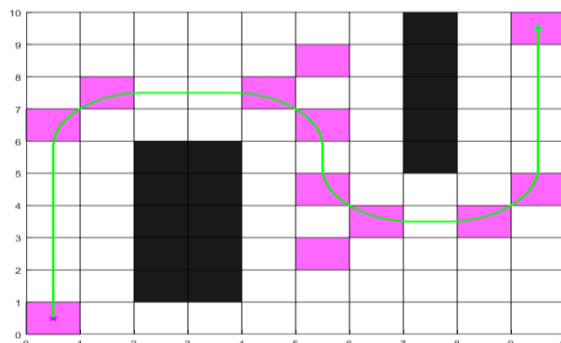


(b) Simulation results for the improved hybrid A* algorithm

Fig. 7. Path planning in a 10*10 environment grid map by using different algorithms.
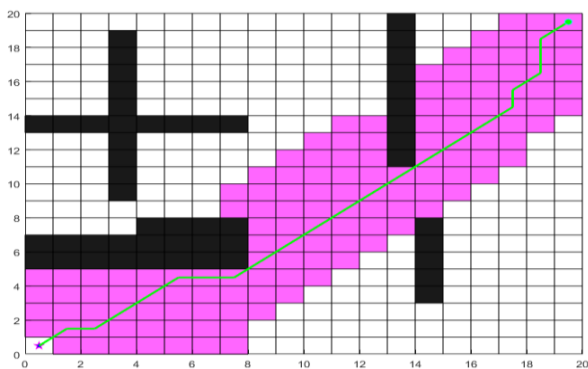


(a) Simulation results for the traditional A* algorithm
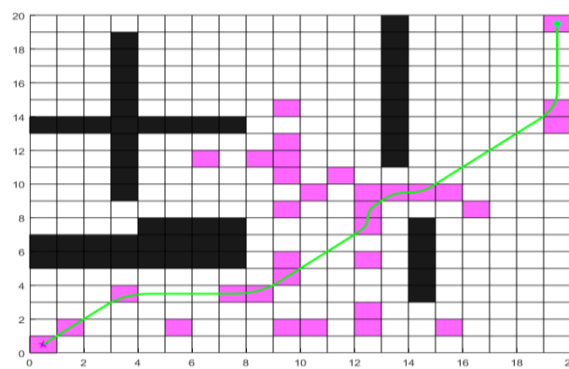


(b) Simulation results for the improved hybrid A* algorithm

Fig. 8. Path planning in a 20*20 environment grid map by using different algorithms.
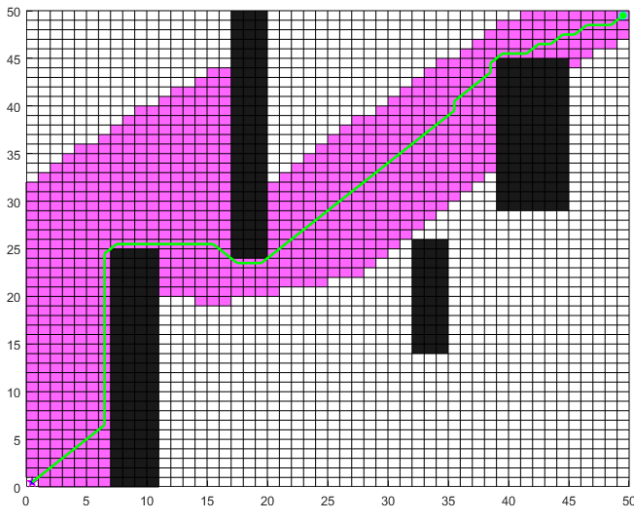
(a) Simulation results for the traditional A* algorithm
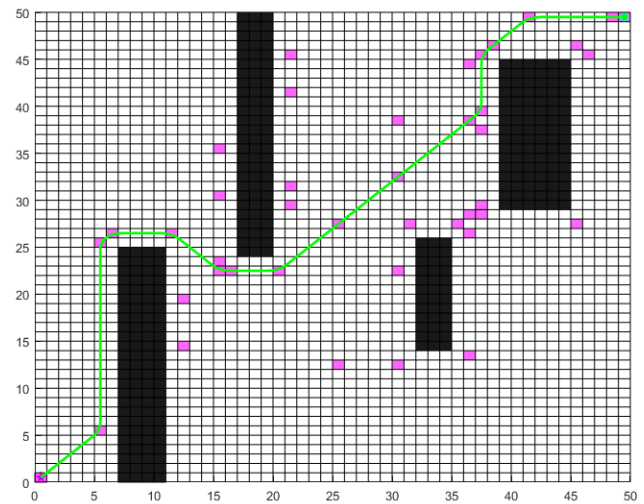


(b) Simulation results for the improved hybrid A* algorithm

Fig. 9. Path planning in a 50*50 environment grid map by using a different algorithm.

TABLE II. DATA COMPARISON BETWEEN TRADITIONAL A* ALGORITHM AND IMPROVED HYBRID A* ALGORITHM

| Map size | Search time /s | | Number of nodes | | Path length | |
|---|---|---|---|---|---|---|
| | *Traditional* | *Improved* | *Traditional* | *Improved* | *Traditional* | *Improved* |
| 10*10 | 0.082 | 0.027 | 61 | 12 | 14.5 | 23.1 |
| 20*20 | 0.198 | 0.046 | 139 | 33 | 28.6 | 29.9 |
| 50*50 | 1.211 | 0.065 | 787 | 42 | 82.7 | 87.0 |

## IV. CONCLUSION

In the complex regional environment of the hotel, even though the traditional A* algorithm is proper to plan a reasonable shortest path, several inflection points are available in the path. That makes the hotel service robot too close to the obstacle during driving and will seriously influence the safe movement of mobile robots. Numerous nodes are evaluated in the process of path planning simultaneously, which makes its real-time performance not good enough. To overcome such problems, the current paper suggests an improved A* algorithm. First, the conventional A* algorithm combines bidirectional search and JPS hop point selection to enhance search efficiency. Then, the traditional A* algorithm is combined with the security weight square matrix to make the path trajectory safer. Finally, cubic spline interpolation is employed to smoothen the turning path trajectory. The experimental results show that the improved algorithm is productive and better than the conventional A* algorithm in the number of search path nodes, path security and path smoothness.

The limits of the proposed algorithm is that it is only applicable to static environment, and does not have the ability to avoid dynamic obstacles. Since there are still dynamic areas in the hotel environment, such as pedestrians and other dynamic obstacles, we will study how to embed dynamic path planning into this algorithm to meet the specific needs of the hotel mission in future studies.

## COMPETING OF INTERESTS

The authors declare no competing of interests.

## AUTHORSHIP CONTRIBUTION STATEMENT

Xiaobing Cao: Writing-Original draft preparation

Conceptualization, Supervision, Project administration.

Yicen Xu: Language review, Methodology, Software

Yonghong Yao: Formal analysis

Chenbo Zhi: Validation

## AVAILABILITY OF DATA AND MATERIALS

On Request

## DECLARATIONS

not applicable

## REFERENCES

[1] B. K. Patle, A. Pandey, D. R. K. Parhi, and A. Jagadeesh, "A review: On path planning strategies for navigation of mobile robot," Defence Technology, vol. 15, no. 4, pp. 582–606, 2019.

[2] X. Sa, W. Huaiyu, and C. Zhihuan, "Research of mobile robot path planning based on improved A* algorithm," in 2020 Chinese Automation Congress (CAC), IEEE, 2020, pp. 7619–7623.

[3] C. Cheng, X. Hao, J. Li, Z. Zhang, and G. Sun, "Global dynamic path planning based on fusion of improved A* algorithm and dynamic window approach," Journal of xi'an jiaotong university, vol. 51, no. 11, pp. 137–143, 2017.

[4] S. Alshammrei, S. Boubaker, L. Kolsi, "Improved Dijkstra Algorithm for Mobile Robot Path Planning and Obstacle Avoidance" Computers Materials & Continua, vol. 72 no. 3, pp. 5939–5954, 2022.

[5] P. Xin, X. Wang, X. Liu, Y. Wang, Z. Zhai, and X. Ma, "Improved bidirectional RRT* algorithm for robot path planning," Sensors, vol. 23, no. 2, p. 1041, 2023.

[6] K. Zhou, L. Yu, Z. Long, and S. Mo, "Local path planning of driverless car navigation based on jump point search method under urban environment," Future Internet, vol. 9, no. 3, p. 51, 2017.

[7] M. Alireza, D. Vincent, and W. Tony, "Experimental study of path planning problem using EMCOA for a holonomic mobile robot," Journal of Systems Engineering and Electronics, vol. 32, no. 6, pp. 1450–1462, 2021.

[8] L. Liu et al., "Global dynamic path planning fusion algorithm combining jump-A* algorithm and dynamic window approach," IEEE Access, vol. 9, pp. 19632–19638, 2021.

[9] H.-M. Zhang, M.-L. Li, and L. Yang, "Safe path planning of mobile robot based on improved A* algorithm in complex terrains," Algorithms, vol. 11, no. 4, p. 44, 2018.

[10] R. Song, Y. Liu, and R. Bucknall, "Smoothed A* algorithm for practical unmanned surface vehicle path planning," Applied Ocean Research, vol. 83, pp. 9–20, 2019.

[11] S. Al-Ansarry, S. Al-Darraji, A. Shareef, D. G. Honi, and F. Fallucchi, "Bi-directional Adaptive Probabilistic Method with a Triangular Segmented Interpolation for Robot Path Planning in Complex Dynamic-Environments," IEEE Access, 2023.

[12] C. Li, X. Huang, J. Ding, K. Song, and S. Lu, "Global path planning based on a bidirectional alternating search A* algorithm for mobile robots," Comput Ind Eng, vol. 168, p. 108123, 2022.

[13] K. Shi, Z. Wu, B. Jiang, and H. R. Karimi, "Dynamic path planning of mobile robot based on improved simulated annealing algorithm," J Franklin Inst, vol. 360, no. 6, pp. 4378–4398, 2023.

[14] A. Janis and A. Bade, "Integration of Enhanced Jump Point Search Algorithm and Modified Bresenham Technique for Path Finding in Grid-Based Map Environment," Adv Sci Lett, vol. 24, no. 3, pp. 1582–1586, 2018.

[15] X. Li, F. Liu, J. Liu, and S. Liang, "Obstacle avoidance for mobile robot based on improved dynamic window approach," Turkish Journal of Electrical Engineering and Computer Sciences, vol. 25, no. 2, pp. 666–676, 2017.

[16] F. P. Vista, A. M. Singh, D.-J. Lee, and K. T. Chong, "Design convergent Dynamic Window Approach for quadrotor navigation," International journal of precision engineering and manufacturing, vol. 15, pp. 2177–2184, 2014.

[17] Z. Yang, J. Li, L. Yang, and H. Chen, "A Smooth Jump Point Search Algorithm for Mobile Robots Path Planning Based on a Two-Dimensional Grid Model," Journal of Robotics, vol. 2022, 2022.

[18] Y. Li, J. Zhao, Z. Chen, G. Xiong, and S. Liu, "A robot path planning method based on improved genetic algorithm and improved dynamic window approach," Sustainability, vol. 15, no. 5, p. 4656, 2023.

[19] F. Duchoň et al., "Path planning with modified a star algorithm for a mobile robot," Procedia Eng, vol. 96, pp. 59–69, 2014.

[20] T. Wang, L. Zhao, Y. Jia, and J. Wang, "Robot path planning based on improved ant colony algorithm," in 2018 WRC Symposium on Advanced Robotics and Automation (WRC SARA), IEEE, 2018, pp. 70–76.

[21] H. Wang, X. Qi, S. Lou, J. Jing, H. He, and W. Liu, "An Efficient and Robust Improved A* Algorithm for Path Planning," Symmetry (Basel), vol. 13, no. 11, p. 2213, 2021.

[22] G. Tang, C. Tang, C. Claramunt, X. Hu, and P. Zhou, "Geometric A-star algorithm: An improved A-star algorithm for AGV path planning in a port environment," IEEE access, vol. 9, pp. 59196–59210, 2021.

[23] T.-W. Kang, J.-G. Kang, and J.-W. Jung, "A Bidirectional Interpolation Method for Post-Processing in Sampling-Based Robot Path Planning," Sensors, vol. 21, no. 21, p. 7425, 2021.

[24] Y. Bai and H. Zhuang, "On the comparison of bilinear, cubic spline, and fuzzy interpolation techniques for robotic position measurements," IEEE Trans Instrum Meas, vol. 54, no. 6, pp. 2281–2288, 2005.

[25] S.-H. Hong, L. Wang, T.-K. Truong, T.-C. Lin, and L.-J. Wang, "Novel approaches to the parametric cubic-spline interpolation," IEEE transactions on Image Processing, vol. 22, no. 3, pp. 1233–1241, 2012.

# Innovative Practice of Virtual Reality Technology in Animation Production

He Huixuan[1], Xiang Yuan[2]

Shijiazhuang University of Applied Technology, Animation Academy, Shijiazhuang City, Hebei Province, 050031, China

*Abstract*—In order to make the users who watch animation look better, the innovative practice research of virtual reality technology in animation production is proposed. According to the object structure information, the method uses 3ds Max software to complete the production of 3D animated character models. It completes the character prototype texture feature extraction through the character prototype boundary contour extraction, image hat height transformation, and discrete grid projection. The OpenGL texture mapping is used to complete the mapping of 3D animated character models. After the boundary optimization of texture seams, the best 3D animated character modeling effect is obtained. Geometric modeling technology and DOF nodes are used to build static and dynamic scene entity models to complete the construction of a 3D animation scene. The interactive visualization platform based on space is introduced to complete the visualization processing of the interactive animation scene, and the animation scene is regarded as the image base. The points with equal arc length are selected according to the curve points, and the camera is switched in combination with the roaming speed to realize the real-time roaming of 3D animation scenes and complete the innovative, practical application of virtual reality technology in animation production. Experimental results show that this method improves the smoothness, integrity, and authenticity of animation, improves the smoothness of motion, and ensures the real-time roaming effect.

*Keywords—Virtual reality technology; animation production; 3D modeling; OpenGL; geometric modeling; real time roaming*

## I. INTRODUCTION

Virtual reality is a new world created by computer and electronic technology. It is a seemingly real simulation environment. Through a variety of sensor devices [1], [2], users can use people's natural skills to investigate and operate objects in the virtual world according to their feelings, participate in events in the virtual world, and provide intuitive and natural real-time perception of seeing, listening, and touching, and make participants "immerse" in the simulation environment [3]. 3D animation modeling technology is to create the structure and shape of objects involved in animation in the process of animation production. The modeling process requires the analysis of the shape characteristics of the object. The existing shape in the computer can be expanded and changed to meet the requirements of realistic modeling. In addition, the structure should also be linked with the geometry in reality. Through the analysis of object categories, different methods of model building and detail modification can be carried out [4].

Many researchers have conducted research on the application of virtual reality technology in animation production, such as Kokaram A et al. [5], who studied motion-based frame interpolation in film and television production. Frame interpolation is the process of synthesizing new frames between existing frames in image sequences. The difference frame is used as a key algorithm module in movie production to improve the effect of movie production. But motion-based frame interpolation usually requires a lot of computation and processing, especially in high-resolution image sequences. This may lead to excessive consumption of computing resources, reduce real-time performance, and increase production costs. For example, Khalid N et al. [6], to improve the accuracy of character modeling in the animation, through the Gaussian mixture model, each pixel of different human body parts is assigned a specific label to achieve better animation character modeling. However, this method has high requirements on the quality of input images. For low-quality, fuzzy or noisy images, the accuracy of joint extraction and pixel-level marking may decrease, thus affecting the accuracy of character modeling. Perez Perez Y et al. [7], to better complete the animation scene, proposed an environment modeling method based on joint semantic and geometric features, based on Markov random field (MRF), strengthen the consistency between environmental semantics (e. g., beam, column, wall, ceiling, floor, pipe), and geometric labels (example, horizontal, vertical, cylindrical), and use the neighborhood context to improve the accuracy of semantic labels, improve the accuracy of environment modeling, provide effective environment modeling basis for animation. However, when the environment is more complex or there are subtle changes, such as texture differences, lighting changes, etc., the method may encounter challenges in the consistency of semantic and geometric labels, resulting in a decline in the accuracy of modeling results.

Aiming at the problems existing in the above methods in 3D animation modeling, this paper combines virtual reality technology to study the innovative practice of virtual reality technology in animation production to provide users with a better 3D animation perception. The research structure of this article includes:

*1) Provide* a detailed introduction to the process and steps of using 3DsMax software to create character models, explain the methods of extracting texture features from character prototypes, including boundary contour extraction, image high-low hat transformation, and discrete mesh projection, and explain the application of OpenGL texture mapping technology and boundary optimization texture seam method;

*2) Explain* the application of geometric modeling technology and the construction process of DOF nodes, and

introduce the establishment of static and dynamic scene entity models;

*3) Deeply* explain the application of spatial based interactive visualization platforms and discuss the interactivity and visualization processing methods of animation scenes;

*4) Introduce* the concept and methods of treating animation scenes as image bases, and explain the application of techniques such as curve point filtering, camera switching, and roaming speed;

*5) Verify* the effectiveness of the techniques presented in this article through experiments;

*6) Discuss* the research results and point out future research directions.

## II. ANIMATION PRODUCTION BASED ON VIRTUAL REALITY TECHNOLOGY

### A. 3D Character Modeling

*1)* 3D animated character model based on 3ds Max*:* To build 3D models of related objects in animation, first, we need to analyze the structural characteristics of objects. The objects in 3D animation can be generally divided into two types: regular objects and irregular objects. There are two main modeling methods for animated 3D characters: the stacking modeling method and the subdivision modeling method. The stacking modeling method creates characters from details to the whole, while the subdivision modeling method first creates an object's overall shape and then carves details [8].

Regular objects are suitable for stacking modeling because of their regular shape. Its modeling process is to split complex objects into some basic components, then use the basic molding command to make these small parts and stack them together. Animation designers must grasp the model's size-scale relationship and spatial location. Common tools include insert, extrusion, turning, chamfering, FFD deformation tools, etc.

Irregular objects are more suitable for the subdivision modeling method; that is, the basic geometry is used to complete the large shape of the object first, and then the model details are subdivided by editing polygons or mesh editing tools. This modeling method is similar to drawing sketches or sculpture's construction process. Generally, we use subdivision modeling to complete the modeling of 3D characters, cartoon characters, or surface object bodies. Common tools include edit mesh, edit polygon, symmetry, mesh smoothing, etc. The specific process is shown in Fig. 1.

After determining the construction method, this paper completes the production of a 3D animated character model by applying the 3ds Max software, obtains the rough image by stretching and changing the graphics tools contained in the 3ds Max software, and then modifies the details with the modification tools, to establish a more accurate and intuitive model.

*2) Character prototype texture extraction:* The texture is an important feature of the scenery. It is generally believed that texture is a certain regularity of grayscale or color distribution on the image, which has different characteristics in complex textures. Texture can be roughly divided into two categories: regular and irregular. The extraction of irregular regional textures is an important part of image processing technology, so it has become a research hotspot of computer application technology.
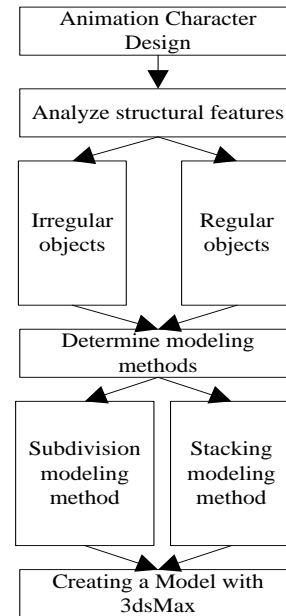


Fig. 1. Animation character modeling process.

*a)* Boundary contour extraction*:* The mathematical expression of the object contour obtained from the object image is called contour extraction [9], which is one of the basic steps in image processing, computer vision, and medical images.

This paper uses a method based on an improved model to extract the contour of the character prototype. Firstly, the method of combining some algorithms with the circumscribed rectangle is used to realize the automatic setting of the control points of the initial contour line of the model and then improve the gradient energy function to introduce the gradient vector flow operator so that the contour can better converge to the target depression, and adjust the weight of other energy function terms according to the actual situation. Finally, the target contour line is obtained through the neighborhood greedy algorithm when the total energy is minimized.

*b) Image preprocessing:* This paper combines high hat transform, and low hat transform to process the image. Add the high hat transform image to the original image, and then subtract the low hat transform image to get the enhanced image. Using the original image plus the result of the high hat transform can make the area with a larger gray value brighter, and subtracting the result of the low hat transform can make the smaller gray value darker. In this paper, the morphological reconstruction method is defined as:

$$C_{top}(f) = S_f(f) + 1 \tag{1}$$

$$I = thresh\left(S_f(f)\right) \tag{2}$$

Among them $S_f(f)$ is from the enhancement diagram at the start of the reconstruction operation, which is equivalent to subtracting a constant from the grayscale of the enhancement image $S_f(f) = f - h$, denoted by $S_f(f - h)$. Here is a marked graph. This paper binarizes the reconstructed result graph to get the marked graph. Because of the filtering effect of the reconstruction operation, many of the original images after the reconstruction operation are smaller than all the small peaks that will be "flattened". The value represents the size of the filtering amount [10]. In terms of filtering effect, reconstruction filtering is low-pass filtering, which flattens the peaks in the image. The peak in the image is the high-frequency part, and flattening the peak is equivalent to filtering out part of the high-frequency part. The low-frequency part is retained to form a low-pass effect.

The dual operation of reconstruction transformation is expressed as, according to the principle of dual operation, $S_f * (f + h)$ the role of will fill the low valley in the image. After operation $S_f * (f + h)$, it will be less than fill in the original low valley and form a platform at the original low valley. The combination of morphological and dual reconstruction can flatten the peak and fill the valley, leaving only the middle part of the image that is neither high nor low. The function of the parameter is to control the contrast. Generally, the contrast in the signal is less than all fluctuations that $2hh$are filtered out.

Reconstruction filtering is essentially an efficient nonlinear filtering, and the filtering effect is similar to median filtering, but the effect is better. The purpose of morphological reconstruction is to extract the maximum value and bright top of the region to smooth the interior of each target and extract the maximum value within the target range.

*c) Texture extraction:* Generally, texture images are stored and represented rectangularly [11]. This exactly corresponds to the discrete grid of the surface, which is the points on the discrete grid are projected onto the image, and the color information of the image is extracted so that the texture is arranged in the form of a discrete grid, but this is too sparse. Therefore, the mesh needs to be refined. Each refined mesh point corresponds to a pixel on the texture image. Original geometric mesh size is $4 \times 3$, to extract texture, each geometric mesh is further uniformly refined $4 \times 4$. The size of the whole refined mesh is $16 \times 12$. Each vertex on the mesh corresponds to a pixel of each vertex that is re-projected onto the image (in the actual solution process, both the vertical grid line and the horizontal grid line corresponding to the grid point can be projected onto the image to find the intersection point on the image). The color information of the point on the image is obtained to form a texture image [12]. The coordinate value of the thinned image point is usually a floating point number. If the color value of one of its neighboring pixels is directly taken as the color value of the current point, the extracted texture will become more blurred.

Therefore, in this paper, color information is extracted in a weighted way according to the position of the current point and the proximity of the four adjacent pixels around it, as shown in Fig. 2, $(x, y)$ is the pixel coordinate of the current image point,

$(x_1, y_0)$ is the coordinate of four adjacent pixels (the coordinate value is an integer).
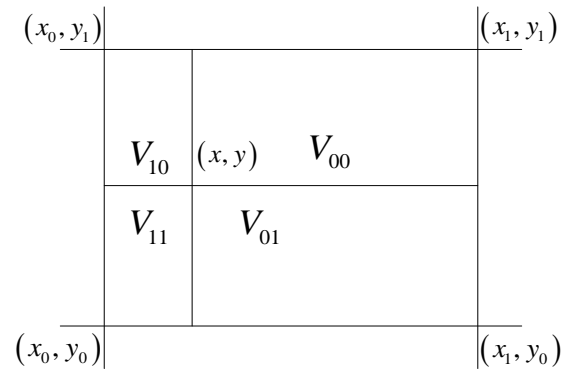


Fig. 2.  Weighted center of gravity.

Set $f(x, y)$ is a point the texture extraction based on barycentric coordinates can be expressed as:

$$f(x,y) = \frac{C_{top}(f)}{I}\frac{V_{00}}{V} f(x_0, y_0) + \frac{V_{01}}{V} f(x_0, y_1) \qquad (3)$$
$$+ \frac{V_{10}}{V} f(x_1, y_0) + \frac{V_{11}}{V} f(x_1, y_1)$$

The whole surface is projected onto the front view, and the barycentric weighted texture extraction method can be used to obtain the image's texture. For the texture data matrix [13] outside the specified area, please give it a uniform value of 0 and give the part of the texture data matrix outside the texture outline in the specified area a value of 1. This aims to facilitate the storage of irregular regional textures and the subsequent mapping of 3D models.

*3) Model mapping and optimization*

*a)* Model mapping based on OpenGL texture mapping: After getting the texture image and 3D model, we need to use its projection relationship to give the corresponding texture information to the corresponding part of the image on the surface of the 3D model, that is, local texture mapping. Texture mapping technology is also called texture mapping technology [14]. In 3D graphics, texture mapping methods are widely used, especially to describe realistic objects. The work of local texture mapping is to correctly back project an acquired texture image onto the surface of the 3D model.

This paper uses OpenGL texture mapping technology to map 3D models. The technology of texture mapping of the texture image refers to mapping the texture image to the surface of a three-dimensional object, that is, predefine the texture pattern on the texture space of a plane area and then establish the mapping relationship between the object surface space and the coordinates of the texture pattern. When the visible points of the object's surface are determined, the texture pattern can be attached to the object's surface according to the value of the corresponding points in the texture space. The general steps of texture mapping are shown in Fig. 3.
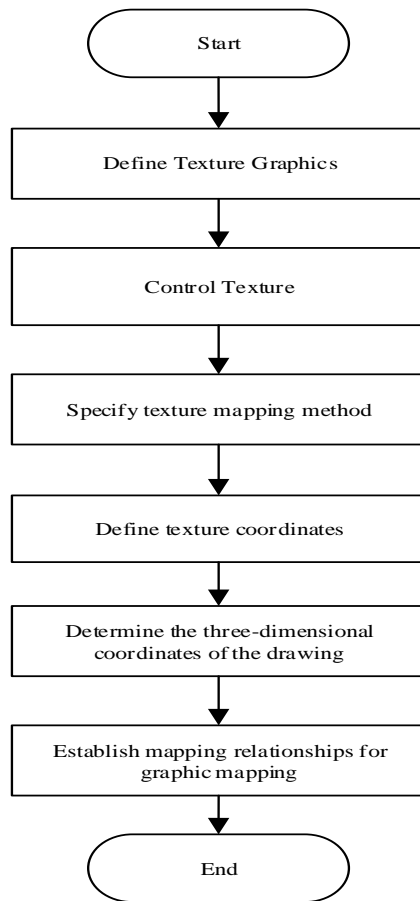
Fig. 3. Texture mapping steps.



Fig. 4. Schematic diagram of concave-convex texture processing.

For relatively flat model areas, texture mapping is relatively easy to implement. This paper introduces merging adjacent triangular patches to deal with irregular mapping areas. Its algorithm idea takes the included angle between the normal vectors of adjacent triangular patches as the object of study. The included angle will remain unchanged if it exceeds a set closed value. If the included angle is less than a certain idle value, it will merge two triangular patches, and so on repeatedly. However, since the included angles of multiple triangular patches may accumulate in the same direction during the merging process, if it is possible to simplify the larger surface into a plane according to the above principles, limiting the size of the composite surface is necessary. When the area of the plane is greater than a set value, the merging stops. According to the corresponding texture area of the model surface, the merged plane can use the trilinear filtering texture filtering technology to operate it in OpenGL to achieve relatively flat texture mapping of the model area. To map the bump model surface, it is necessary to comprehensively consider the texture's stretching, scaling, bending, and the change of gray value. See Fig. 4 for details.

As shown in Fig. 4, a texture segment $O * P *$ is for the curve segment of the bump model; the texture segments attach to the curve segment $O * P *$, assume that in the curve segment: $O * Q *= w, Q * R *= v, R * P *= u$.

To stretch a texture segment $OP$, which also means reducing the length of the distance between and $P *$. Make line segment $OP$ and $O *$ and $P *$ the included angle between is $\theta$, then represent:

$$\sin \theta = \frac{|OP|}{|O*P*|} = \frac{f(x,y)\sqrt{(x_1-x_2)^2(y_1-y_2)^2}}{\sqrt{(x_1*-x_2*)^2(y_1*-y_2*)^2(z_1*-z_2*)^2}} \quad (4)$$

To make the length of texture deformation the same as the curve, the interpolation coefficient is introduced here. Setting rules are as follows:

When a surface moves from a point to point $Q *$, take $s = o$;

When a surface moves from a point to point $R *$, take $s = q$;

When a surface moves from a point to point $P *$, take $s = r$;

And:

$$ow + qv + ur = |OP| \quad (5)$$

$$o + q + r = 1 \quad (6)$$

Can get

$$\sin \theta = \frac{|OP|}{|O*P*|} = \frac{ow+qv+ur}{\sqrt{(x_1*-x_2*)^2(y_1*-y_2*)^2(z_1*-z_2*)^2}} \quad (7)$$

After the above transformation, the texture space coordinates can be mapping area coordinates with the bump model one-to-one correspondence to better realize bump model mapping.

*b)* Boundary optimization*: Because of the color difference of the texture at the back boundary of the texture mapping of the 3D character model, it is easy to have color discontinuity between the texture regions; that is, texture seams when rendering realistically. If not properly handled, it will greatly impact the reality of the 3D modeling of the character. Therefore, the purpose of processing texture boundaries is to eliminate texture seams in the display effect as far as possible.

The parameterization method is used to map the mesh model to the plane domain or other domains to process the model with some mature technologies in the parameter domain [15]. Parameterization is to establish a one-to-one correspondence between the vertices of the mesh model and the points on the parameter domain and ensure that the mesh formed by the vertices on the parameter domain is not folded. The deformation of the parameterized mesh is smaller than that of the original mesh. According to the different parameter domains, parameterization can be plane and spherical.

Planar parameterization is to spread the mesh model into a planar mesh. Each triangle uniquely corresponds to a triangle in the planar domain, which is helpful for texture mapping of the mesh. Spherical parameterization can map the completely closed mesh to the spherical domain, which is conducive to mesh simplification, shape gradient, and other processing.

According to the idea of parameterization, the implementation steps of texture seam processing at the back boundary of 3D character model texture mapping can be established: locate the triangle mesh belt on both sides of each boundary. The grid belt is parameterized in two dimensions; In parameter domain, texture is constructed by weighted interpolation method to achieve natural transition [16]. So far, this paper has completed the optimization of texture mapping.

### B. 3D Animation Scene Construction based on Virtual Reality

The 3D solid model in a virtual scene generally includes static and dynamic solid modeling. Static refers to solid models of terrain and ground objects, ranging from houses, pavilions, and launchers to roadside flowers and trees. Dynamic solid models refer to various simulation solid models with motion attributes, such as pedestrians, robots, swing booms, etc.

*1) Construction of scene static entity:* The physical building is the main part of the virtual scene and the most important scene content. The modeling of static entities mainly uses geometric modeling technology [17]. Geometric modeling studies basic problems such as graphic data structure and deals with the representation of polygons, triangles, and points of objects' geometry and morphology, as well as their appearance, textures, materials, and colors. In the geometric modeling of solid buildings, it is required that the real and accurate space position and surface texture be used to represent the objective object of buildings to create an environment in which the observer can feel immersive and immersive. Geometric modeling is mainly realized by corresponding modeling software such as 3DMAX, AutoCAD, etc. 3D modeling of buildings is carried out in combination with AutoCAD and 3DMax [18]. The overall process includes total station acquisition of characteristic data points, importing AutoCAD and AutoLISP software to form wireframes, importing 3DMax to establish 3D models, 3DMax texture mapping, and model output. The overall process is shown in Fig. 5.
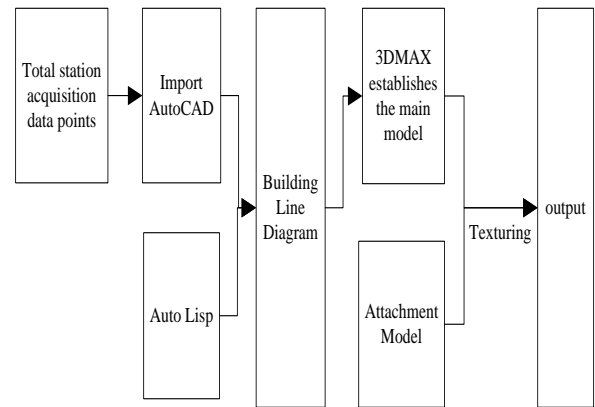


Fig. 5.   Building 3D modeling based on AutoCAD and 3DMax.

*2) Construction of dynamic entities:* The modeling of moving parts should first construct moving objects. The construction of moving objects may change the initially built internal organization [19], that is, add DOF nodes of moving parts in the file formed by modeling, set corresponding local coordinates and locate them, and carry out the kinematic relationship (Link analysis) on multiple moving parts based on DOF to determine the kinematic traction relationship, determine and publish the main parts. The process of non-publicly distributed sub-components and traction equation is shown in Fig. 6.
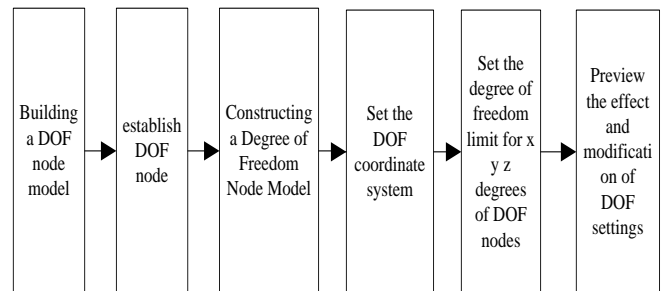


Fig. 6.   General process of establishing DOF nodes.

### C. Interactive Animation Scene Visualization

Animation design aims to establish a spatially based interactive visualization platform [20], integrating relational databases, spatial location files, component modules, various multi-dimensional graphical visualization tools, and common graphical expression tools. The above module takes relational data as the analysis object, applies spatial spatial analysis principles and methods to extract spatial information, and displays it as layers. The object is further analyzed and transformed through graphical visualization methods, such as a parallel coordinate method, to explore the inherent abstract rules of spatial data. These abstract rules are just beyond the reach of traditional spatial analysis and expert experience. Finally, appropriate visualization technology is selected to express the rules so that the rules or patterns contained in the data can be transformed into graphics that are easy to understand and recognize and visualized through animation. Fig. 7 is the visualization structure diagram of an interactive animation scene.
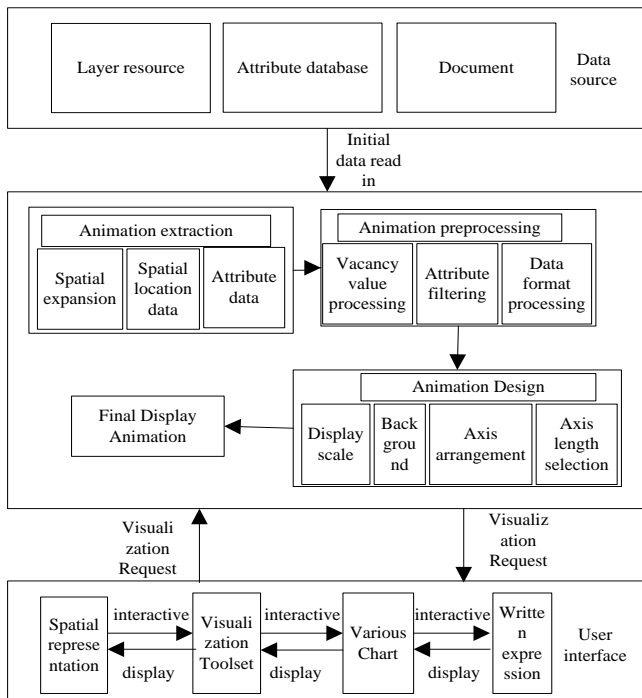
Fig. 7. Interactive animation scene visualization structure diagram.

As shown in Fig. 8, the main function of the space module is to provide a layer-calling function and a simple layer-editing function, such as refreshing, mouse response, highlighting, etc.; The main function of the visualization toolset module is to focus on implementing HyperTree and parallel coordinate method and provide a toolset management function to add or delete tools dynamically; The main function of the interaction function module is to realize the interaction between visualization tools and spatial layers, as well as between visualization tools.
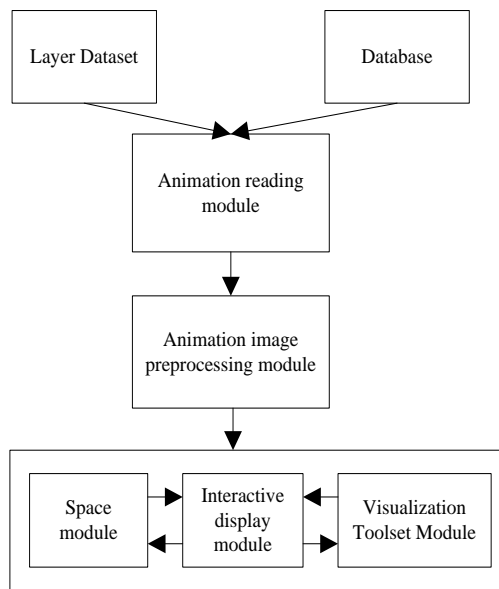


Fig. 8. Functional module structure diagram.

Layers and various multidimensional visualization tools each play an important role in interactive animation scene visualization. Layers display animation data and express spatial attributes of spatial objects. Graphic visualization tools are suitable for expressing nonspatial multidimensional attributes. Interactive animation scene visualization focuses on combining layers and multidimensional visualization tools [21] to develop their interactive functions. The interactive function in interactive animation scene visualization is shown in the following points:

*1) HyperTree* is used to manage hierarchical layer resources;

*2) HyperTree* highlighted nodes interact with corresponding layers [22];

*3) The* highlighted area on the layer interacts with the parallel coordinate, which displays the nonspatial attribute data of the area;

*4) HyperTree highlights nodes to interact with parallel coordinates, which express the attribute information of corresponding layers;*

*5) The* parallel coordinate method is used to compare and analyze the attribute data of each region on each layer [23].

To summarize, the layer you see, the highlighted node in the center of HyperTree, and the parallel coordinate visualization tool are all aimed at the same animation target object. After realizing interactive expression among layers, HyperTree expression, parallel coordinate expression, and common charts, the user's thinking is more coherent, and various tools give full play to their due advantages, showing a more advantageous interactive animation scene visualization effect.

### D. Real-time Roaming of 3D Animation Scene

In the process of real-time roaming of the animation scene, first select three animation scenes in the three-dimensional space to form an image base, calculate the image overlap area, fuse the area, use this as the basis for image stitching [24], extract the color information of the animation scene image, calculate the sampled image data [25], obtain the curve points of the scene image, and filter points with equal arc length according to the curve points, Switch the camera according to the points with equal arc length and the roaming speed to complete the real-time roaming of 3D animation scene. The specific steps are detailed as follows:

Assumed represents 3D global coordinates, $(x'_1, x'_2)$ represents two-dimensional plane coordinates, $e$ represent the time variable, then use equation (8) to select three animation scenes in three-dimensional space to form an image base, calculate the overlapping area between images, and use equation (8) to express

$$\partial * (\mu) = \frac{[X'_1, X'_2, X'_3] \otimes (x'_1, x'_2)}{sin\,\theta\, e\sigma[\gamma]} \qquad (8)$$

Where $\sigma[\gamma]$ represents an image sequence.

Assumed represents the position of a point in the scene from the viewpoint, $a$ represents the distance between the agreed viewpoint and the object, represents the brightness

difference of two adjacent images, then use Formula (9) to fuse the regions and sew the images according to this:

$$\overline{m}(G) = \frac{A(\wp)\times\eta}{a\times\partial} - \partial*(\mu)\mu(\alpha) \otimes [\Gamma(\theta)] \quad (9)$$

Where $\partial$ represents the tensor parameter, the camera position, and any point in the viewpoint grid.

Hypothesi $n$ represents any time of roaming $\overline{m}(T)$ represents a viewpoint, the coordinates of this point determine a point on the image taken by the lens, and the color of this point is defined as the pixel color corresponding to the point expressed by Formula (10):

$$m*(\delta) = \frac{\overline{m}(T)\times n\overline{m}(G)}{\partial(\Upsilon)} \quad (10)$$

Where $\partial(\Upsilon)$ represents the pixel values of different image regions, $t(b)$ represents the color value between unit squares.

Assume the edge represents boundary conditions, Represents the tangent value of the curve, calculate the sampled image data using Equation (11), obtain the curve points of the scene image, and filter points with equal arc length according to the curve points:

$$g(c) = \frac{\theta(l)\times\Gamma m*(\delta)}{L(\sigma)} \times \varphi(\gamma)*\Phi(\mu) \quad (11)$$

Where $L(\sigma)$ represents the camera storage format, the arc length curve point set, and the jitter state in the walkthrough.

Assumed that represents the rotation angle of image coordinates, $\delta(j)$ represent the density value of curve points, use formula (12) to switch cameras according to points with equal arc length and roaming speed to complete real-time roaming of 3D animation scene:

$$\eta(\overline{m}) = g(c)\frac{\delta(j)*M(K)}{C(\mu)} \times \xi(\vartheta) \quad (12)$$

Where $\xi(\vartheta)$ represents roaming parameters, $C(\mu)$ represents the cumulative distance between points.

The above method is the principle of real-time roaming of 3D animation scenes, which is used to complete real-time roaming of 3D animation scenes [26].

## III. EXPERIMENTAL ANALYSIS

To verify the innovative practice effect of this method in animation production, take the Judy police officer role and animation scene in the "Crazy Animal City" animation as an example; use this method to model, texture map, and virtual roaming interaction, and give the Judy police officer and scene produced by this method, as shown in Fig. 9.



(a) Character modeling

(b) Scene modeling

Fig. 9.   Effect of the method mapping in this article.

It can be seen from the analysis of Fig. 9 that this method uses OpenGL texture mapping technology for mapping, which improves the effect of 3D animation design of characters and scene modeling, making both clearer and more realistic.

The method in this paper is used to conduct real-time roaming experiments on some scenes and characters in Crazy Animals to verify the practicability of animation scene construction, and the effect is shown in Fig. 10.



(a) 15 frames

(b) 25 frames

(c) 35 frames



(d) 45 frames

Fig. 10. Real-time roaming rendering.

As can be seen from Fig. 10, this paper selects three animation scenes in the three-dimensional space to form an image base. It combines the roaming speed to switch the camera and the points with the middle arc length of the image curve points to achieve real-time roaming to ensure the practical effect of real-time roaming.

The texture mapping of the character model is optimized by optimizing the boundary processing method in this paper to eliminate the texture seams in the display effect. The effect before and after optimization is shown in Fig. 11.



(a) Pre optimization rendering



(b) Optimized rendering

Fig. 11. Effect before and after optimization.

By analyzing Fig. 11, it can be seen that the boundary optimization method in this paper has a good effect on eliminating texture seams. It is clearer for the expression of the appearance and texture of animated characters, enhances the texture of animated characters, and verifies that the texture mapping map in this paper is more practical, making the animation effect smoother and giving users a better impression.

To verify the collision detection performance of the method in this paper, the experiment conducted collision detection on a virtual scene, and the results are shown in Fig. 12.

It can be seen from Fig. 12 that collision detection for real-time roaming in the virtual scene is carried out by the method in this paper. The detection time is only 4ms, and the detection time is less than 10ms. It can be seen that this method has good performance in collision detection of virtual scenes.
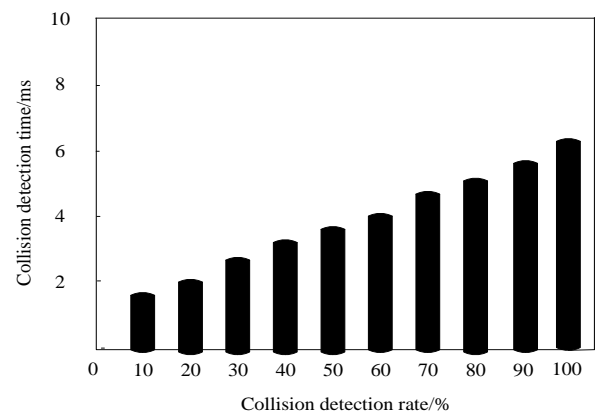


Fig. 12. Collision detection time and collision detection rate.

To verify the smoothness of the motion connection of the 3D animated character model in this method, the motion process of Police Officer Judy was tested. There are 30 frames in each motion clip, and the number of clips is 8, totaling 240 frames. The connection smoothness in the ear joint and eye rotation motion segment of police officer Judy in the post-application test of this method is shown in Fig. 13.
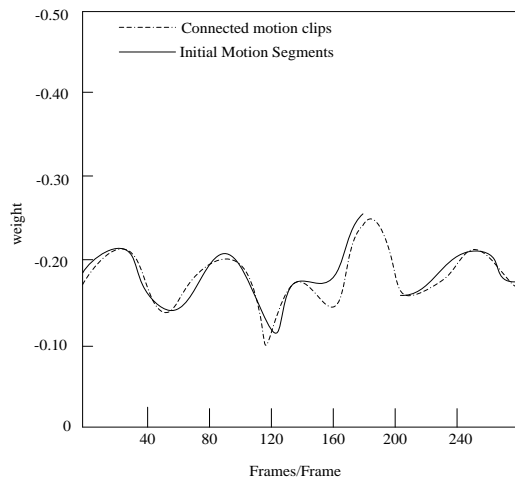


(a) The Movement Process of Ear Cartilage Joints
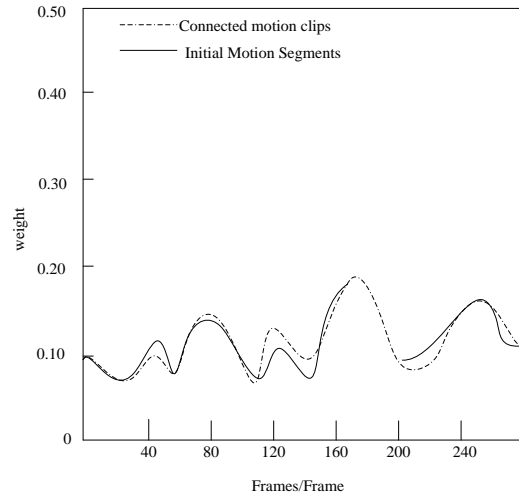


(b) The movement process of eye rotation

Fig. 13. Connection smoothness of two motion segments.

From the analysis of Fig. 13, it can be seen that through the method in this paper, the connection between the two motion segments is relatively smooth, and the initial motion is also retained accordingly. The experimental results show that the connection smoothness of each part of the motion segment is high under the method in this paper. Applying this method to animation production can enhance the visual perception of animation and bring a good visual experience.

## IV. CONCLUSION

Aiming at the problems of low fluency and rough models in 3D modeling animation production, the innovative practice of virtual reality technology in animation production is studied to improve the animation user perception. Animated character modeling, image texture extraction, mapping, and optimization are realized through 3ds Max software. The animation scene is constructed from the two entry points of dynamic entity and static entity, and through interactive animation scene visualization design and 3D animation scene real-time roaming design, the innovative practice of virtual reality technology in animation production is finally realized. Through experimental verification, this method can improve the quality of animation production and enhance the visual perception of users. In addition, in future animation production, researchers can work to introduce more complex and realistic physical effects, such as cloth simulation and liquid simulation, to provide more realistic visual effects for animation production, and enhance the user's immersion and viewing experience.

### COMPETING OF INTERESTS

The authors declare no competing of interests.

Authorship Contribution Statement. Xiang Yuan: Writing-Original draft preparation, Conceptualization, Supervision, Project administration.

He Huixuan: Language review, Methodology, Software

### DATA AVAILABILITY

On Request

### DECLARATIONS

Not applicable

### REFERENCES

[1] D. A. Purwaningsih, "Puppet movements in structure-specific traditional paper cut out animation production," Ultimart: Jurnal Komunikasi Visual, vol. 13, no. 2, pp. 61–68, 2020.

[2] F.-L. Wu, H. Liang, C. Ge, F. Liang, Q. Zhang, and J.-Z. Lu, "Semantic Framework Promotes Interactive Puppetry Animation Production to Assist Storytelling Training.," Journal of Information Science & Engineering, vol. 36, no. 6, 2020.

[3] M. Akdere, K. Acheson, and Y. Jiang, "An examination of the effectiveness of virtual reality technology for intercultural competence development," International Journal of Intercultural Relations, vol. 82, pp. 109–120, 2021.

[4] L. Zhang, M. Boutaous, and S. H. Xin, "3D Modeling of Polymer Selective Laser Sintering Process: Laser-Polymer Interaction Modeling," Key Eng Mater, vol. 926, pp. 349–357, 2022.

[5] A. Kokaram, D. Singh, S. Robinson, D. Kelly, B. Collis, and K. Libreri, "Motion‐based frame interpolation for film and television effects," IET Computer Vision, vol. 14, no. 6, pp. 323‐338, 2020.

[6] N. Khalid, Y. Y. Ghadi, M. Gochoo, A. Jalal, and K. Kim, "Semantic recognition of human-object interactions via Gaussian-based elliptical modeling and pixel-level labeling," IEEE Access, vol. 9, pp. 111249–111266, 2021.

[7] Y. Perez-Perez, M. Golparvar-Fard, and K. El-Rayes, "Segmentation of point clouds via joint semantic and geometric features for 3D modeling of the built environment," Autom Constr, vol. 125, p. 103584, 2021.

[8] A. M. Pessoa, I. M. Guerreiro, C. F. M. e Silva, and F. R. P. Cavalcanti, "A Positive Semidefinite Autocorrelation Function for Modeling 3D Gaussian processes," IEEE Trans Veh Technol, vol. 70, no. 2, pp. 1941–1945, 2021.

[9] R.-W. Bello, A. S. A. Mohamed, and A. Z. Talib, "Contour extraction of individual cattle from an image using enhanced Mask R-CNN instance segmentation method," Ieee Access, vol. 9, pp. 56984–57000, 2021.

[10] A. Bajaj, R. Khurana, and M. E. Ali, "Quantum Interference and Spin Filtering Effects in Photo-responsive Endoperoxide Based Single Molecular Device," 2021.

[11] M. Khojastehnazhand and M. Roostaei, "Classification of seven Iranian wheat varieties using texture features," Expert Syst Appl, vol. 199, p. 117014, 2022.

[12] G. Guingo, F. Larue, B. Sauvage, N. Lutz, J.-M. Dischler, and M.-P. Cani, "Content-aware texture deformation with dynamic control," Comput Graph, vol. 91, pp. 95–107, 2020.

[13] J. Yang, S. Zhong, V. Luzin, J. Li, X. Liu, and C. Dan, "HRTex: a high-resolution texture data processing tool for monochromatic neutron diffraction based on the pixel projection method," J Appl Crystallogr, vol. 55, no. 2, pp. 425–435, 2022.

[14] K. Chaiyasarn, A. Buatik, H. Mohamad, M. Zhou, S. Kongsilp, and N. Poovarodom, "Integrated pixel-level CNN-FCN crack detection via photogrammetric 3D texture mapping of concrete structures," Autom Constr, vol. 140, p. 104388, 2022.

[15] L. Dumitru, "Evolution of force‑free field parameter in active regions with major eruptive events," Astronomische Nachrichten, vol. 342, no. 3, pp. 485–496, 2021.

[16] Z. Ni, Y. Liu, J. Xie, Y. Liao, and J. Dai, "Investigation on the Design Method and Failure Mechanism of Silicon-Based MEMS Setback Arming Device," in International Conference on Mechanical Design, Springer, 2021, pp. 2357–2374.

[17] H. Liu, S. Xu, and S. Liu, "An online course mode based on microlecture videos: Using CAD geometric modeling course as an example," Computer Applications in Engineering Education, vol. 29, no. 5, pp. 1300–1311, 2021.

[18] W. Xu, P. Liu, and Z. Lu, "Research on digital modeling and optimization of virtual reality scene," International Journal of Advanced Network, Monitoring and Controls, vol. 3, no. 4, pp. 69–76, 2019.

[19] S. Zhu, G. Yu, W. Tang, J. Hu, and E. Luo, "Thermoacoustically driven liquid-metal-based triboelectric nanogenerator: A thermal power generator without solid moving parts," Appl Phys Lett, vol. 118, no. 11, 2021.

[20] K. Zhao et al., "Interactively mechanochromic electronic textile sensor with rapid and durable electrical/optical response for visualized stretchable electronics," Chemical Engineering Journal, vol. 426, p. 130870, 2021.

[21] H. Dou, B. Xu, F. Shen, and J. Zhao, "V-SOINN: A topology preserving visualization method for multidimensional data," Neurocomputing, vol. 449, pp. 280–289, 2021.

[22] G. Gottlob, M. Lanzinger, R. Pichler, and I. Razgon, "Complexity analysis of generalized and fractional hypertree decompositions," Journal of the ACM (JACM), vol. 68, no. 5, pp. 1–50, 2021.

[23] S. Zou, H. Liu, Y. Liu, J. Yao, and H. Wu, "Singularity Analysis and Representation of 6DOF Parallel Robot Using Natural Coordinates," Journal of Robotics, vol. 2021, pp. 1–11, 2021.

[24] L. Nie, C. Lin, K. Liao, and Y. Zhao, "Learning edge-preserved image stitching from multi-scale deep homography," Neurocomputing, vol. 491, pp. 533–543, 2022.

[25] X. Zhou et al., "Extracting photometric redshift from galaxy flux and image data using neural networks in the CSST survey," Mon Not R Astron Soc, vol. 512, no. 3, pp. 4593–4603, 2022.

[26] A. Rosinol et al., "Kimera: From SLAM to spatial perception with 3D dynamic scene graphs," Int J Rob Res, vol. 40, no. 12–14, pp. 1510–1546, 2021.

# A Machine Learning Approach for Emotion Classification in Bengali Speech

Md. Rakibul Islam[1], Amatul Bushra Akhi[2], Farzana Akter[3], Md Wasiul Rashid[4], Ambia Islam Rumu[5],
Munira Akter Lata[6], Md. Ashrafuzzaman[7]

Dept. of Computer Science and Engineering, Daffodil International University, Dhaka, Bangladesh[1, 2, 4]
Dept. of IoT and Robotics Engineering, Bangabandhu Sheikh Mujibur Rahman Digital University, Bangladesh[3]
Dept. of English, Daffodil International University, Dhaka, Bangladesh[5]
Dept. of Educational Technology, Bangabandhu Sheikh Mujibur Rahman Digital University, Bangladesh[6, 7]

*Abstract*—In this research work, we have presented a machine learning strategy for Bengali speech emotion categorization with a focus on Mel-frequency cepstral coefficients (MFCC) as features. The commonly utilized method of MFCC in speech processing has proved effective in obtaining crucial phoneme-specific data. This paper analyzes the efficacy of four machine learning algorithms: Random Forest, XGBoost, CatBoost, and Gradient Boosting, and tackles the paucity of research on emotion categorization in non-English languages, particularly Bengali. With CatBoost obtaining the greatest accuracy of 82.85%, Gradient Boosting coming in second with 81.19%, XGBoost coming in third with 80.03%, and Random Forest coming in fourth with 80.01%, experimental evaluation shows encouraging outcomes. MFCC features improve classification precision and offer insightful information on the distinctive qualities of emotions expressed in Bengali speech. By demonstrating how well MFCC characteristics can identify emotions in Bengali speech, this study advances the field of emotion classification. Future research can investigate more sophisticated feature extraction methods, look into how temporal dynamics are incorporated into emotion classification models, and investigate practical uses for emotion detection systems in Bengali speech. This study advances our knowledge of emotion classification and paves the way for more effective emotion identification systems in Bengali speech by utilizing MFCC and machine learning techniques. Our work addresses the need for thorough and efficient techniques to recognize and classify emotions in speech signals in the context of emotion categorization. Understanding emotions is essential for many applications, as they are a basic component of human communication. By investigating cutting-edge strategies that show promise for enhancing the precision and effectiveness of emotion recognition, this study advances the field of emotion classification.

*Keywords—XgBoost; gradient boosting; CatBoost; random forest; MFCC*

## I. INTRODUCTION

Emotions significantly impact people's attitudes and decision-making processes in various everyday activities, making them a crucial aspect of communication among individuals. Emotional understanding promotes mutual understanding and contributes to a fulfilling social life [1]. In today's technologically advanced world, where voice commands and manual instructions are exchanged between humans and machines, the ability of artificial intelligence or machine learning to identify and assess someone's emotional state from their voice has emerged as a pressing challenge [2][3]. There is little study on emotion classification in non-English languages like Bengali, which presents particular difficulties for speech analysis. Systems currently in use frequently struggle with linguistic diversity and cultural subtleties. In order to solve these problems, our research advances the area by introducing a machine learning technique that improves the accuracy of emotion recognition. Our objective is to enhance emotional intelligence and human-machine communication, especially in underrepresented languages.

The contributions of this paper are twofold. Firstly, we provide a comprehensive investigation into the application of machine learning algorithms for emotion classification in Bengali speech, which is a relatively unexplored area of research. This study addresses the need for emotion recognition systems tailored to Bengali, which can enhance communication and human-machine interactions within Bengali-speaking populations. Secondly, we offer insights into the performance of Random Forest, XGBoost, CatBoost, and Gradient Boosting models in the context of emotion classification in Bengali speech. By comparing and evaluating the results of these models, we aim to identify the most effective approach for accurate emotion recognition.

Overall, our research aims to contribute to the advancement of speech emotion recognition, specifically in the Bengali language, and pave the way for improved human-machine interactions, affective computing applications, and speech therapy within Bengali-speaking communities.

This paper is organized logically and cogently. It starts with an introduction that sets the scene by supplying the backdrop and rationale for the research, outlining the goals of the study in detail, and highlighting its importance. The literature review section that follows conducts a detailed examination of earlier work on speech emotion identification, discusses several methods for categorizing emotions, and identifies the research gap in Bengali speech emotion categorization. The basis for the following sections is laid by this. Details regarding the Bengali speech dataset used in the study are provided in the dataset and data collecting section,

along with information on the methods used for data collection and participant selection, as well as the preprocessing procedures performed on the speech data. The feature extraction section emphasizes the importance of Mel-frequency cepstral coefficients (MFCC) features in the categorization of emotions by emphasizing their extraction from the preprocessed speech data. In the section on machine learning algorithms, the algorithms Random Forest, XGBoost, CatBoost, and Gradient Boosting are introduced and discussed, along with details on their implementation and parameter settings. The experimental setup, evaluation measures, and results of the implemented algorithms are examined in the experimental evaluation section. The discussion part concludes by interpreting the results, outlining any ramifications, and addressing any study limitations.

The motivation section underlines the importance of emotions in human communication and draws attention to the dearth of research on emotion classification in non-English languages, particularly Bengali. The Speech Emotion Recognition (SER) methodology—which includes data collection, preprocessing, feature extraction, model selection, training, evaluation, optimization, and deployment—is the primary topic of discussion in Section IV. With the goal of accurately detecting emotions, enhancing human-machine interactions, and enhancing emotional comprehension, the project focuses on creating a machine learning technique for Bengali speech emotion categorization.

In Section V, we go over the steps involved in classifying emotions in Bengali speech. These include gathering data, analyzing dataset properties, extracting features using MFCC, and applying machine learning algorithms (Random Forest, XGBoost, CatBoost, and Gradient Boosting) to the classification process. The diversity of the dataset, the value of MFCC in capturing emotional information, and the prowess of each classification method in handling complex patterns are all emphasized in this section.

## II. MOTIVATION

The need to address the dearth of studies concentrating on non-English languages, notably Bengali, in the field of emotion classification led to the research on "A Machine Learning Approach for Emotion Classification in Bengali Speech". Despite the importance of emotions in human communication, the majority of study so far has focused on English or other commonly used languages. This investigation into the categorization of emotions in Bengali speech tries to close this gap.

The major goal is to create a machine learning model that can recognize emotions in Bengali speech that is accurate and efficient. A useful tool for deciphering and comprehending emotions communicated in Bengali would be provided by such a model. It has applications in areas including sentiment analysis for Bengali-based platforms and services, human-computer interaction, and virtual assistants.

The study also recognizes the diversity of languages and cultures found among Bengali speakers. For effective emotion classification, Bengali's limited linguistic resources, dialectal variances, and pronunciation quirks present special

difficulties. In order to create emotion recognition algorithms that are both culturally diverse and contextually pertinent, the project intends to solve these issues.

Studies on the identification of emotions from Bangla speech data are scarce [4],[24]-[27]. 25 MFCCs were suggested by researchers who investigated the optimum number of MFCCs for emotion recognition in speech data in [4]. To categorize user comments on Facebook pages, a deep neural network model based on Gated Recurrent Units was created in [24]. 5126 comments in Bangla were gathered, and these were divided into six categories: incitement, political, religious, hate speech, communal attack, and incitement. The accuracy of the GRU-based model was 70.10%. With an accuracy of 51.33%, a Recurrent Neural Network (RNN) was used in [25] to categorize six emotions in Bangla speech: joy, sadness, anger, surprise, fear, and disgust. [26] used a vocabulary of 500 distinct words using the Gaussian Mixture Model-Hidden Markov Model and Deep Neural Network-Hidden Markov Model to identify emotions in 49 distinct speakers. Using Word Error Rate to gauge model performance, they discovered that the GMM-HMM had 3.96% WER while the DNN-HMM had 5.30% WER. In [27], speech data was subjected to emotion categorization using an ensemble method that used multiple supervised classifiers, with an accuracy rate of 70%. It is clear that the level of accuracy attained by previous studies in audio-based emotion detection and recognition has not been very high.

In conclusion, the research is driven by the need to enhance communication technology, enable applications that can better recognize, interpret, and react to human emotions within the Bengali-speaking community, and advance our understanding of emotions in Bengali speech.

## III. RELATED WORK

While there have been extensive research studies conducted in the field of Speech Emotion Recognition (SER) for various languages, particularly English, only limited efforts have been made to establish SER for Bengali (Bangla). In 2018, Rahman et al. introduced a method for Bangla emotion classification using Dynamic Time Warping (DTW) assisted Support Vector Machines (SVM) [5]. The features utilized for classification were the first and second derivatives of Mel-frequency Cepstral Coefficients (MFCC). The proposed system achieved an average accuracy of 86.08% on a small dataset consisting of only 200 words.

N. Kholodna et al. [6] constructed a machine-learning model to automate the detection of emotions from speech, to monitor public emotions. They selected a manually annotated dataset and transformed it into a textual representation using a vectorization technique. Deep learning approaches, including convolutional neural networks (CNNs), recurrent neural networks (RNNs), and perceptron models, were employed to identify emotions from the textual data. The classification accuracy of the resulting model was found to be relatively low, with random forest achieving 77%, regression achieving 74%, and the naive Bayesian classifier achieving 73.5%.

Some researchers work with Bengali speech. That study employs pitch and MFCC variables to identify emotions in

Bengali speech [7]. The suggested method produced an accuracy rate of 87.50% on a self-created dataset of Bengali emotional speech, with accuracies of 80.00% for joyful, 75.00% for sad, 85.00% for angry, and 75.00% for neutral emotions. For a thorough evaluation of the study, further information is required.

A. Majeed et al. [8], a system was created by the authors to detect emotions from Roman Urdu text. They constructed a comprehensive corpus comprising 18k sentences, sourced from various domains, and annotated it with six different emotion classes. The authors further employed baseline algorithms such as K-Nearest Neighbors (KNN), Decision Tree, Support Vector Machine (SVM), and Random Forest on their corpus. The achieved accuracy rate was 69.4%, with an F-measure of 0.69

S. Cunningham et al. [9], the authors introduced an Artificial Neural Network (ANN) approach for predicting emotions in the domain of Music Emotion Recognition. A total of 167 voices were analyzed, and 76 features were extracted from the International Affective Digital Sounds Dataset (IADS). To facilitate model training and evaluation, the audio dataset was partitioned into three segments: training (70%), validation (15%), and testing (15%). During the prediction phase, the ANN model achieved accuracy rates of 64.4% for arousal and 65.4% for valence. These results indicated that the shallow neural network outperformed the regression model in terms of performance.

In our study, we were successful in classifying Bengali speech emotions with a high degree of accuracy. We achieved outstanding results by utilizing cutting-edge machine learning methods including Random Forest, XGBoost, CatBoost, and Gradient Boosting. Our top accuracy score was 82.85%. This outstanding performance demonstrates how well our method works at correctly identifying and categorizing emotions in Bengali speech. These findings help Bengali language emotion recognition technology progress and present prospects for real-world applications in numerous fields.

## IV. SPEECH EMOTION RECOGNITION

The goal of speech emotion recognition (SER), a crucial field of study, is to automatically identify and categorize the emotions indicated in speech signals. To process and analyze the voice data properly, the system includes a number of crucial steps. In the beginning, a dataset of labeled speech recordings is gathered, capturing emotions displayed in regulated or naturalistic settings. To improve their quality and retrieve pertinent information, the speech signals go through preprocessing procedures such as segmentation and noise removal. The preprocessed signals are used to extract acoustic features such as Mel Frequency Cepstral Coefficients (MFCCs), energy-based features, and prosodic features. These characteristics act as clear illustrations of the emotional content. When deep learning or machine learning models like Support Vector Machines, Convolutional Neural Networks, or Long Short-Term Memory networks are used for classification, model selection is critical. The models are developed using the labeled data, tuned using hyperparameters, and their performance is assessed. In the end, the trained models can be used to predict emotions from speech data that hasn't been seen, which will help with applications like affective computing, human-computer interaction, and speech therapy. The processes of data collection, preprocessing, feature extraction, model selection, training, assessment, optimization, and deployment are all included in speech-emotion recognition systems. This study aims to investigate a machine learning method for Bengali speech emotion classification. The work seeks to accomplish accurate emotion detection using methods like MFCC-based feature extraction and models like Random Forest, XGBoost, CatBoost, and Gradient Boosting. Understanding and creating efficient speech emotion detection algorithms have the potential to significantly improve human-machine interactions, and emotional comprehension, and facilitate applications in many other fields.

## V. THE MATERIALS AND METHOD

To identify the proper emotional state, our suggested system goes through several significant phases, including generating a dataset for Bengali speech, feature extraction, feature classification, and decision-making based on extracted features and classifications. Fig. 1 is the process of emotion classification.
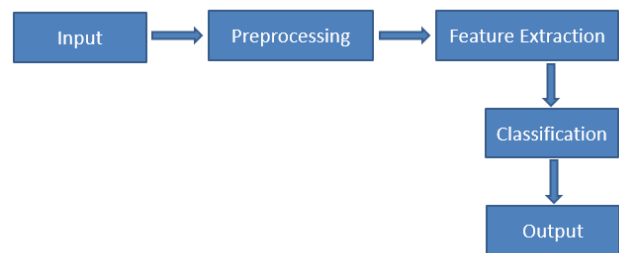


Fig. 1. Process of emotion classification.

### A. Preparing Datasets

*1) The* technique of collecting the data for Bengali speech's classification of emotions requires several processes and meticulous planning. A total of 40 sentences were originally composed, and 25 of them were chosen for recording. Following this, these lines were uttered and recorded by people ranging in age from 9 to 48, creating a total of 25 distinct recordings. The clips ranged in length from 2 to 4 seconds, with an average of about 3 seconds, and each recording was converted to the mp3 format.

A Sample of data -

Bangla- তোমার নাম কি?

English – What is your name?

Phonemic- Tomar name ki?

Fig. 2 shows the audio frequency of each emotion.

(a) Audio frequency output (angry)



(b) Audio frequency output (happy)



(c) Audio frequency output (neutral)



(d) Audio frequency output (sad)
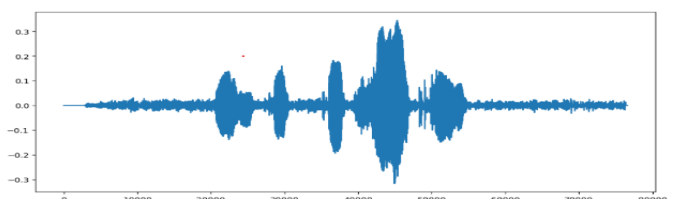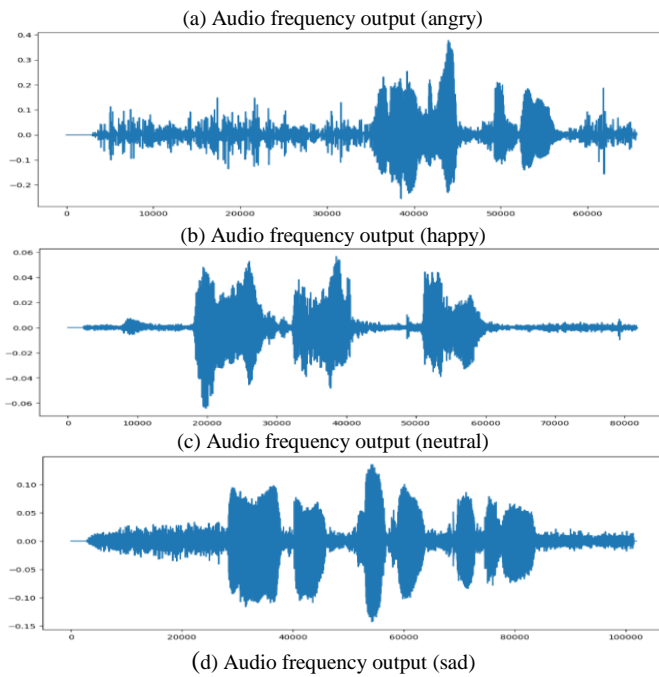
Fig. 2.   Audio frequency output (angry, happy, neutral, sad).

Our Bengali speech dataset's main sources include unrestrained or natural emotions, performed or driven emotions, and elicited or created emotions [10]. Happy, Sad, Natural, and Angry were the four main emotions that were the focus of the data gathering. 14 speakers, including both male and female speakers, were enlisted to take part in the recording process to capture a wide spectrum of emotions. When compared to comparable datasets like the BanglaSER database, our dataset has a considerable volume [11]. This research produced a sizable dataset of 1400 audio recordings, 350 of which were assigned to each emotion group. Fig. 3 represents the total dataset and accuracy of each algorithm.

| SL | Name of Algorithm | Number of data | Accuracy (%) |
|----|-------------------|----------------|--------------|
| 1 | Random Forest | 350 | 80.01 |
| 2 | XGBoost | 350 | 80.03 |
| 3 | Gradient Boosting | 350 | 81.19 |
| 4 | CatBoost | 350 | 82.85 |

Fig. 3.   Total Number of dataset and accuracy of each algorithm.

The data collection method required a lot of time and effort because the participants were not actors but rather members of the general public. In order to capture a realistic depiction of genuine emotional expression, it was essential to guarantee the speaker's independence. The dataset is important because it is diverse in terms of speakers and emotions. The dataset offers a wide range of vocal qualities and expressions with four female voices and ten male sounds. An 80-20 split was used to ensure the dataset's usefulness, with 80% of the data (1120 clips) going toward training the models and the other 20% (280 clips) going toward testing and assessment.

### B. Extraction of Features

Feature extraction is the process of taking a little amount of information from a speech signal in order to address each speaker separately [12]. Mel-frequency cepstral coefficients (MFCC) are a frequently employed method for feature extraction, which is a vital stage in the analysis and classification of speech data. In order to extract pertinent acoustic features that capture the unique qualities of the audio signals, MFCC is used in the context of emotion categorization in Bengali speech. Parts of human speech production and perception are represented by MFCC. The human auditory system's logarithmic perception of loudness and pitch is depicted by MFCC [13].

MFCC features are based on human hearing perception [14]. The first step in the MFCC feature extraction procedure is to split the recorded speech data into brief frames, which typically last 20–40 milliseconds and have a minimal amount of overlap. The next step is to perform a series of operations on each frame to determine the MFCC coefficients. A full diagram of MFCC is given in Fig. 4.

The average frequency perception capability of humans is over the range of 1KHz [15]. To lessen spectral leakage, the speech signal is first divided into manageable chunks, and a windowing function, such as the Hamming window, is then applied. The signal is then transformed from the time domain to the frequency domain on each segment using the Fast Fourier Transform (FFT).
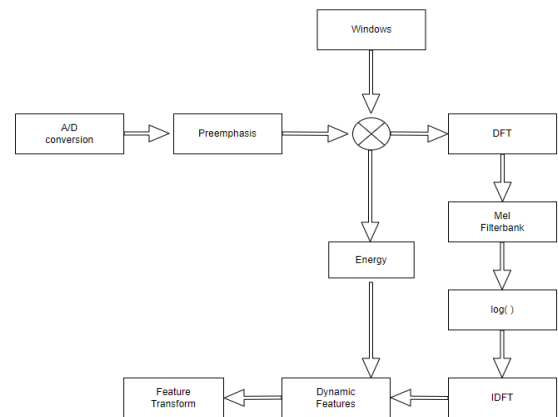


Fig. 4.   Block diagram of MFCC.

The resulting frequency spectrum is then altered using a Mel filter bank to simulate the non-linear perception of sound by the human auditory system. The purpose of this filter bank is to simulate how sensitive different frequencies are to the human ear. The magnitude of the spectral components is represented by the logarithm of the energy contained within each Mel filterbank.

The Discrete Cosine Transform (DCT) is used to decorrelate the Mel-frequency coefficients as the last stage in the MFCC feature extraction process. This treatment decreases

dimensionality, compresses the data, and keeps the most important information.

The signal produced by our speech often comprises a large number of criteria that indicate the signs of different emotions. Pitch, energy, format, as well as spectral features including Mel-frequency cepstrum coefficients (MFCC), are recovered in this study. The approach known as MFCC (Mel-frequency cepstral coefficients) is commonly used in speech recognition and voice emotion recognition. It is predicated on the knowledge that speech impulses are not linearly processed by the human auditory system. A non-linear Mel scale filter bank is used, which amplifies the lower frequencies while attenuating the higher ones, to capture the phoneme-specific information included in the lower frequency components of speech.

The short-term power spectrum of a speech frame is represented by the Mel frequency cepstrum in speech processing. It can be found by taking the logarithm of the power spectrum on a Mel frequency scale and performing a linear cosine transform. The formula m = 2595 * log10(f/700+1) converts the normal frequency (f) to the Mel frequency (m). We are able to convert any frequency to its Mel equivalent using the presented equation. [16].

$$m = 2595 log10(\frac{f}{700} + 1)$$

### C. Classification Method

Four well-known algorithms were used to categorize emotions in Bengali speech using machine learning: Random Forest, XGBoost, CatBoost, and Gradient Boosting. These algorithms were selected because they handled classification jobs well and could identify intricate patterns in the data. Many of the researchers use many algorithms but small work with those algorithms.

*1) Random forest:* An ensemble learning system called Random Forest mixes various decision trees to produce predictions. Each tree in the forest is trained using a portion of the data, and the combined forecasts of all the individual trees are used to make the final prediction. Fig. 5 shows the Random Forest architecture. Double randomness is the random forest's primary attribute [17]. Random Forest is renowned for its resistance to overfitting and capacity for handling large-scale, multidimensional data. In Fig. 7, it shows the confusion matrix of Random Forest.
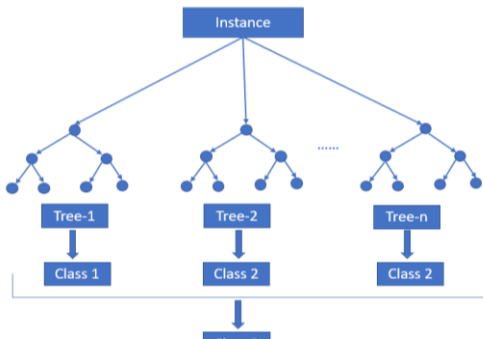


Fig. 5.   RF classifier  architecture.

*2) XGBoost:* It is an ensemble machine-learning technique based on decision trees that makes use of an improved gradient-boosting framework [18]. Due to its outstanding results in numerous machine learning contests, the gradient boosting technique known as XGBoost (Extreme Gradient Boosting) has become increasingly popular. In Fig. 6, Gradient descent is used to incrementally improve an ensemble of poor prediction models, such as decision trees. The capacity of XGBoost to handle intricate relationships and identify non-linear patterns in the data is well known. The major benefit of this algorithm is its regularization technique [19]. Fig. 8 shows the confusion matrix of XGBoost.
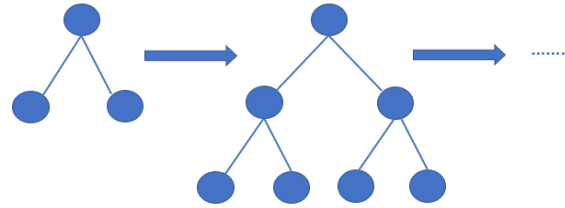


Fig. 6.   XGBoost architecture.

*3) CatBoost:* Another gradient boosting method created specifically to handle category features effectively is CatBoost. It combines ordered boosting and gradient-based optimization techniques to obtain high accuracy in classification applications. When working with datasets that combine numerical and categorical variables, CatBoost is especially helpful. By applying the process of encoding, this method is able to handle the many types of data in the form as they emerge. Such a category can be handled without difficulty by Catboost [20]. Fig. 9 shows the confusion matrix of CatBoost.

*4) Gradient boosting:* A broad ensemble learning approach called gradient boosting combines several weak learners to produce a powerful predictive model. It is among the effective models created for making predictions. Three components make up the technique [21]. A decision tree to strengthen weak learners, a differentiable loss function, and an additive model to help choose the best decision tree model [22]. Each decision tree's nodes use a unique subset of characteristics to determine the appropriate split. In this method, each tree is distinct and capable of extracting a distinctive signal from the data points. Additionally, every new tree is built on top of the mistakes made by the prior tree, and all of these procedures are carried out sequentially [23]. In Fig. 10, it shows the confusion matrix of Gradient Boosting.

### VI.   RESULT AND DISCUSSION

An experimental study was carried out to gauge how well the machine learning approach performed in classifying emotions in Bengali speech. The dataset used for this assessment was made up of recorded Bengali speech samples from different people, covering a variety of emotions including happy, sad, natural, and angry.

For the emotion categorization challenge, four well-known machine learning algorithms—Random Forest, XGBoost, CatBoost, and Gradient Boosting—were used. Using features taken from the Bengali speech samples, such as Mel-frequency cepstral coefficients (MFCC), each algorithm was trained on the training subset. Following the training phase, the classification models were used to forecast the emotions present in the Bengali speech samples using the testing subset. The accuracy of each algorithm was determined by contrasting the anticipated labels of the test samples with their actual labels.

### A. Accuracy

A model's overall accuracy in foretelling both positive and negative events is measured by accuracy. It is determined by dividing the total number of forecasts by the number of correct guesses. Although accuracy offers a broad evaluation of model performance, it may not be appropriate when classes are unbalanced.

$$Accuracy = \frac{TP + TN}{TP + FP + TN + FN}$$

### B. Precision

Precision measures a model's ability to categorize positive cases among all instances that it properly predicted as positive. It is determined by dividing the total number of true positives (positives that were successfully predicted) by the sum of true positives and false positives (positives that were mistakenly forecasted). The model's precision indicates its capacity to prevent false positives.

$$Precision = \frac{TP}{TP + FP}$$

### C. Recall

The capacity of a model to properly identify every positive case is measured by the recall. It is determined by dividing the total number of true positives by the total number of false negatives, which are positives that were mistakenly labeled as negatives. Recall shows how well the model can prevent false negatives.

$$Recall = \frac{TP}{TP + FN}$$

### D. F-1 score

The F1 score is a statistic that combines precision and recall. By using the harmonic mean of precision and recall, it offers a fair evaluation of the model's performance. The F1 score is calculated as 2 * ((precision * recall) / (precision + recall)). It has a scale of 0 to 1, with 1 representing the highest attainable score.

$$F - 1\ Score = 2 * \frac{Recall * Precision}{Recall + Precision}$$

These findings show how well Bengali speech can be classified according to emotions using machine learning. The most accurate results came from CatBoost, which demonstrated a great capacity to identify underlying patterns and relationships in the data. The ability of Gradient Boosting, XGBoost, and Random Forest to correctly predict emotions in

Bengali speech was also demonstrated by their respectable performance.
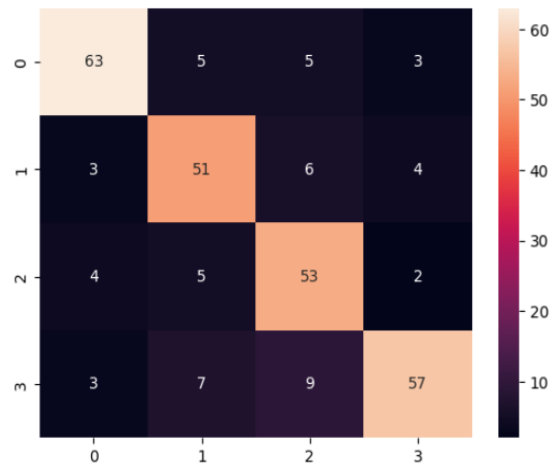


Fig. 7. Confusion matrix of random forest.
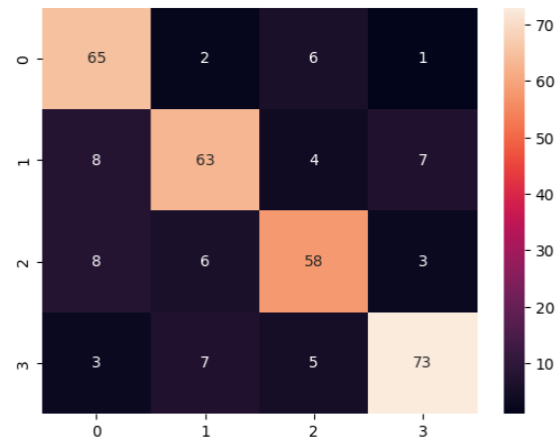


Fig. 8. Confusion matrix of XGBoost.
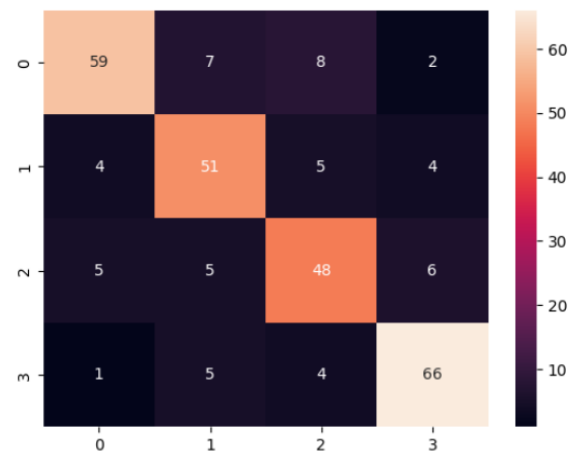


Fig. 9. Confusion matrix of CatBoost.
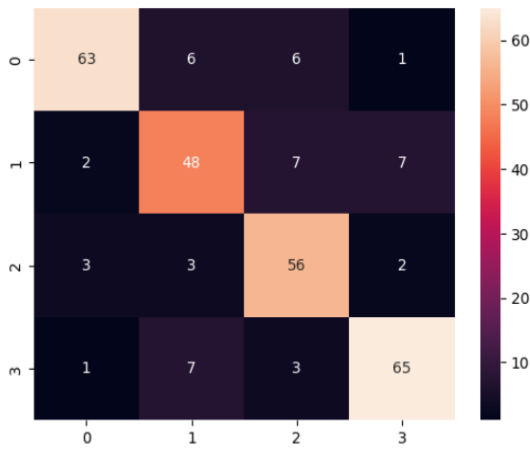
Fig. 10. Confusion matrix of gradient boosting.

TABLE I. CONFUSION MATRIX

| ML Model | Emotion | Precision | Recall | F1-score | Average accuracy |
|---|---|---|---|---|---|
| Random Forest | angry | 0.86 | 0.83 | 0.85 | 0.80 |
| | happy | 0.75 | 0.80 | 0.77 | |
| | neutral | 0.73 | 0.83 | 0.77 | |
| | sad | 0.86 | 0.75 | 0.80 | |
| XGBoost | angry | 0.86 | 0.78 | 0.81 | 0.80 |
| | happy | 0.75 | 0.80 | 0.77 | |
| | neutral | 0.74 | 0.75 | 0.74 | |
| | sad | 0.85 | 0.87 | 0.86 | |
| Gradient | angry | 0.77 | 0.88 | 0.82 | 0.81 |
| | happy | 0.81 | 0.77 | 0.79 | |
| | neutral | 0.79 | 0.77 | 0.78 | |
| | sad | 0.87 | 0.83 | 0.85 | |
| CatBoost | angry | 0.77 | 0.88 | 0.82 | 0.82 |
| | happy | 0.81 | 0.77 | 0.79 | |
| | neutral | 0.79 | 0.77 | 0.78 | |
| | sad | 0.87 | 0.83 | 0.85 | |
| | | | | | |

The experimental evaluation sheds important light on the effectiveness of various algorithms and emphasizes the significance of choosing the right machine-learning methods for Bengali speech emotion categorization. To acquire a deeper knowledge of the models' performance, additional research and assessment could be conducted to study different evaluation measures, such as precision, recall, and F1 score.

We shall start by outlining the judicial system of our suggested model. We have taken into account the Table I accuracy, precision, recall, and F-1 score.

The experimental results showed how each algorithm performed in terms of accuracy. Gradient Boosting, CatBoost, Random Forest, and XGBoost all produced results with

accuracy higher than 81.19%, 82.85%, 80.01%, and 80.03% respectively.

Overall, the experimental findings support the effectiveness of the machine learning method for correctly detecting emotions in Bengali speech, advancing emotion identification systems designed for the Bengali language.

## VII. CONCLUSION AND FUTURE WORK

In conclusion, this research focused on developing a machine-learning approach for emotion classification in Bengali speech. The experimental evaluation demonstrated the effectiveness of the Random Forest, XGBoost, CatBoost, and Gradient Boosting algorithms in accurately predicting emotions in Bengali speech samples. The achieved accuracy rates ranged from 80% to 83%, with CatBoost exhibiting the highest accuracy. This research contributes to addressing the scarcity of studies on emotion classification in non-English languages, specifically Bengali, and provides valuable insights into the potential of machine learning algorithms for capturing emotions in Bengali speech.

Incorporating sequence modeling techniques, such as recurrent neural networks or transformers, as well as taking into account the temporal dynamics of emotions in a speech could capture the temporal dependencies and boost the precision of emotion classification.

We realize that our study has some limitations. There are a total of seven different emotional categories; initially, we concentrated on the classification of four distinct emotions. Second, while MFCC was the main methodology we used for feature extraction, there are other feature extraction methods like LPC and PLP that can provide different insights and advantages.

In future work, we plan to expand our approach by incorporating a broader range of algorithms for emotion classification. Additionally, we intend to explore additional feature extraction techniques, including LPC and PLP, to enhance the robustness and accuracy of our emotion classification system.

## REFERENCES

[1] M. Sidorov, S. Ultes, and A. Schmitt, "Emotions Are A Personal Thing: Towards Speaker-Adaptive Emotion Recognition," in Proceedings of the IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP), 2014, pp. 4836-4840. doi: 10.1109/ICASSP.2014.6854514.

[2] D. Czerwinski and P. Powroźnik, "Human Emotions Recognition with the Use of Speech Signal of Polish Language," in Proceedings of the IEEE Conference on Electrical Power and Energy Conference (EPMCCS), 2018, pp. 1-6. doi 10.1109/EPMCCS.2018.8596404.

[3] A. Agarwal and Dr. A. Dev, "Emotion recognition and conversion based on segmentation of speech in the Hindi language."

[4] M.R. Hasan, M.M Hasan, M.Z. Hossain, "How many Mel-frequency cepstral coefficients to be utilized in speech recognition?," The Journal of Engineering, 12, 817-827, 2021,doi:10.1049/tje2.12082..

[5] M.M. Rahman, D.R. Dipta, and M.M. Hasan, "Dynamic time warping assisted SVM classifier for Bangla speech recognition," in Proceedings of the International Conference on Computer, Communication, Chemical, Material and Electronic Engineering (IC4ME2), 2018, pp. 1-6.

[6] N. Kholodna, V. Vysotska, and S. Albota, "A Machine Learning Model for Automatic Emotion Detection from Speech," in CEUR Workshop

Proceedings, vol. 2917, pp. 699-713, 2021.

[7] J.Y.O.T.I.R.M.A.Y. Devnath, S. Hossain, M.O.S.H.I.U.R. Rahman, H.A.S.I. Saha, M.A. Habib, and N. Sultan, "Emotion recognition from isolated Bengali speech."

[8] S. Cunningham, H. Ridley, J. Weinel, and R. Picking, "Supervised machine learning for audio emotion recognition," Personal and Ubiquitous Computing, vol. 25, no. 4, pp. 637-650, 2021. doi 10.1007/s00779-020-01389-0.

[9] S. Cunningham, H. Ridley, J. Weinel, and R. Picking, "Supervised machine learning for audio emotion recognition," Personal and Ubiquitous Computing, vol. 25, no. 4, pp. 637-650, 2021. doi 10.1007/s00779-020-01389-0.

[10] M. Swain, A. Routray, and P. Kabisatpathy, "Databases, features, and classifiers for speech emotion recognition: a review," International Journal of Speech Technology, vol. 21, 2018.

[11] R.K. Das et al., "BanglaSER: A speech emotion recognition dataset for the Bangla language," Data in Brief, vol. 42, p. 108091, 2022.

[12] A. Bala, A. Kumar, and N. Birla, "Voice command recognition System Based on MFCC and DTW," International Journal of Engineering Science and Technology, vol. 2, no. 12, pp. 7335-7342, 2010.

[13] M. Ghai et al., "Emotion recognition on speech signals using machine learning," in Proceedings of the International Conference on Big Data Analytics, Cloud Computing and Science (ICBDACI), 2017, pp. 34-39. doi 10.1109/ICBDACI.2017.8070805.

[14] R. Choudhary, G. Meena, and K. Mohbey, "Speech emotion based sentiment recognition using deep neural networks," Journal of Physics: Conference Series, vol. 2236, p. 012003, Mar 2022.

[15] M.A. Imtiaz and G. Raja, "Isolated Word Automatic Speech Recognition (ASR) System using MFCC, DTW & KNN," in Proceedings of the Asia Pacific Conference on Multimedia and Broadcasting (APMediaCast), 2016.

[16] N. Yang et al., "Recognize basic emotional states in a speech by machine learning techniques using mel-frequency cepstral coefficient features," Journal of Intelligent & Fuzzy Systems, vol. 39, no. 2, pp. 1925-1936, 2020.

[17] R.R. Choudhary, G. Meena, and K.K. Mohbey, "Speech emotion based sentiment recognition using deep neural networks," Journal of Physics: Conference Series, vol. 2236, p. 012003, Mar 2022.

[18] S. Yan et al., "Speech Interactive Emotion Recognition System Based on Random Forest," in Proceedings of the International Wireless Communications and Mobile Computing (IWCMC), 2020. doi 10.1109/iwcmc48107.2020.9148117.

[19] "Data Analysis and Classification using XGBoost," [Online]. Available: https://www.kaggle.com/code/lucidlenn/data-analysis-and-classification-using-xgboost/notebook. [Accessed: March 7, 2023].

[20] M. Mohan, P. Dhanalakshmi, and R. Satheesh Kumar, "Speech Emotion Classification using Ensemble Models with MFCC," Procedia Computer Science, vol. 218, pp. 1857-1868, 2023. doi: 10.1016/j.procs.2023.01.163.

[21] V. Pujari et al., "Speech Emotion Recognition," International Research Journal of Engineering and Technology (IRJET), vol. 09, no. 3, pp. 3288-3294, 2022.

[22] P.T. Krishnan et al., "Emotion classification from speech signal based on empirical mode decomposition and non-linear features," Complex Intelligent Systems, vol. 7, pp. 1919-1934, 2021. doi: 10.1007/s40747-021-00295-z.

[23] J.H. Friedman, "Greedy function approximation: A gradient boosting machine," The Annals of Statistics, vol. 29, no. 5, pp. 1189-1232, 2001. doi: 10.1214/aos/1013203451.

[24] A.M. Ishmam, S. Sharmin, "Hateful Speech Detection in Public Facebook Pages for the Bengali Language," in 18th IEEE international conference on machine learning and applications (ICMLA), 555-560, 2019, doi:10.1109/ICMLA.2019.00104.

[25] H.M. Hasan, M.A. Islam, "Emotion recognition from bengali speech using rnn modulation-based categorization," In 2020 third international conference on smart systems and inventive technology (ICSSIT), 1131-1136, 2020, doi:10.1109/ICSSIT48917.2020.9214196.

[26] J.R. Saurav, S. Amin, S. Kibria, M.S. Rahman, "Bangla speech recognition for voice search," in 2018 international conference on Bangla speech and language processing (ICBSLP), 1-4, 2018, doi:10.1109/ICBSLP.2018.8554944.

[27] N.T Ira, M.O. Rahman, "An efficient speech emotion recognition using ensemble method of supervised classifiers," in 2020 Emerging Technology in Computing, Communication and Electronics (ETCCE), IEEE, 1-5, 2020, doi:10.1109/ETCCE51779.2020.935091

# Hybrid Integrated Aquila Optimizer for Efficient Service Composition with Quality of Service Guarantees in Cloud Computing

Xiaofei Liu[1]*

School of Computer and Information, Anqing Normal University
Anqing 246133, Anhui, China

*Abstract*—The prompt evolution of cloud computing technology has given rise to the emergence of countless cloud-based services. However, guaranteeing Quality of Service (QoS) awareness in service composition poses a substantial difficulty in cloud computing. A solitary service cannot effectively handle the complicated requests and varied demands of real-world situations. In some instances, one service alone may not be enough to fulfill users' particular requirements, prompting the integration of several services to satisfy these needs. As an NP-hard problem, service composition has been addressed using many metaheuristic algorithms. In this context, the proposed methodology presents a new blended technique, referred to as Integrated Aquila Optimizer (IAO), which amalgamates conventional Aquila Optimizer (AO) and Particle Swarm Optimization (PSO) algorithm. The central objective of this hybridization is to tackle the shortcomings confronted by both AO and PSO algorithms. Specifically, these algorithms are known to get stuck in local search areas and show limited solution variety. To address these challenges, the proposed method introduces a novel transition mechanism that facilitates suitable adjustments between the search operators, ensuring continual improvements in the solutions. The transition mechanism allows the algorithm to switch between AO and PSO when any of them gets stuck or when the diversity of solutions decreases. This adaptability enhances the overall performance and effectiveness of the hybrid approach. The proposed IAO method is exhaustively tested through experiments conducted using the Cloudsim simulation platform. The numerical findings confirm the effectiveness of the suggested approach regarding dependability, accessibility, and expenses, which are essential factors of cloud computing.

*Keywords—Cloud computing; service composition; Particle Swarm Optimization; Aquila optimizer*

## I. INTRODUCTION

Cloud computing is a prevalent method for providing on-demand resources and services. Its pay-as-you-go strategy has attracted considerable attention from businesses and research institutions, particularly in areas that require substantial and intricate computing tasks, such as aerospace, bioinformatics, and physics [1]. Elastic computing capabilities are provided to cloud users through cloud computing, encapsulating these capabilities as Virtual Machines (VMs) deployed on Physical Hosts (PHs) controlled by the management center. These resources are fabricated and made accessible to users based on their availability and the required quality parameters [2]. Cloud computing has become a popular choice for large institutions and IT companies for its reliability, cost-effectiveness, and security. The rise of dependable and credible cloud providers has greatly diminished concerns about embracing this method [3, 4].

However, two significant challenges must be addressed regarding service accessibility and efficient allocation prospects. Predicting all the necessary services, particularly in software services, is a challenging task [5]. To tackle this issue, providing simple and fundamental services that can be combined to form more complex services is essential [6]. Different service providers can contribute to these building block services, making it easier to address the diverse needs of users. The second hurdle is selecting the ideal combination of mandatory and individual services, each supplied by different suppliers with variable quality of service (QoS) features [7]. This involves optimizing the formation of complex services while considering a vast number of similar single services offered by different providers. As an NP-hard problem, this presents a formidable computational challenge. Service composition has emerged as one of the most effective approaches proposed and utilized by cloud providers and researchers alike. This approach simultaneously resolves both of the aforementioned challenges. This technique aims to ensure service user satisfaction by choosing appropriate services from a pool, adhering to service composition restrictions, analyzing important QoS metrics, and accounting for the unpredictable nature of changing service features and network conditions [8].

The integration of the Internet of Things (IoT), machine learning, deep learning, and neural networks represents a transformative paradigm in addressing the complex challenges of cloud service composition. IoT devices generate vast amounts of data, often in diverse formats and characteristics [9-11]. Machine learning techniques provide the ability to extract valuable insights from this data, facilitating intelligent decision-making in the cloud service composition process [12, 13]. Deep learning, a subset of machine learning, excels at handling complex, unstructured data, such as images, text, and speech, enabling the automatic recognition of patterns and correlations in the cloud service context [14, 15]. Neural networks, inspired by the human brain's interconnected neurons, offer powerful tools for modeling and optimizing the intricate relationships between various cloud services,

enhancing the accuracy of service composition while adapting to dynamic and unpredictable conditions [16, 17].

Meta-heuristic algorithms are vital to solving complicated challenges associated with cloud service composition. These algorithms, known for their adaptability and problem-solving versatility, offer effective strategies to optimize the selection and arrangement of diverse cloud-based services, ensuring QoS requirements are met, and performance is maximized within complex cloud computing environments. By efficiently navigating the vast solution spaces, meta-heuristic algorithms contribute significantly to achieving optimal service combinations, which are essential for fulfilling the dynamic and multifaceted demands of cloud users [18]. This paper proposes a swarm intelligence-based method for service composition in cloud computing called Integrated Aquila Optimizer (IAO). IAO merges the traditional AO and Particle Swarm Optimization (PSO) algorithms to overcome their individual constraints. Specifically, IAO addresses the issues of having low solution diversity and being stuck in local search areas. The proposed method incorporates a new transition mechanism to maintain improvements and enhance performance. This mechanism enables appropriate transitions between search operators, allowing the algorithm to switch between AO and PSO when any algorithm becomes stuck or solution diversity decreases. This paper contributes the following:

- QoS criteria determine the optimal selection of services. This ensures that the user's objectives are met effectively.

- Reductions in response times and cost-of-service choices lead to faster service composition.

- Power consumption is decreased compared to other metaheuristic algorithms.

The rest of the paper in arranged in the following manner. Section ii reviews the related work. Section III explains the problem statement. Section IV discusses the proposed method. Simulation results are reported in Section V. Finally, Section VI concludes the paper and suggests some hints for upcoming research.

## II. RELATED WORK

Bao, et al. [19] proposed a new approach called the Evolutionary Multitasking Algorithm for Cloud Computing Service Composition Problem (EMA-CCSC). EMA-CCSC stands out due to its capacity to optimize two service composition tasks concurrently, unlike traditional solvers that handle composite service requests one at a time after pooling them in a waiting queue. This enhanced optimization capability allows EMA-CCSC to handle a greater number of tasks more quickly, leading to improved efficiency. To evaluate the performance of EMA-CCSC, the researchers conducted experiments using the QWS dataset. They resolved a series of randomly generated service composition tasks varying in size and structure. Experiments suggest that EMA-CCSC is superior to other algorithms with varying properties. Notably, EMA-CCSC achieves this performance while spending only half of its computational expenses. Qi, et al. [20] introduce

models for evaluating Quality of Service (QoS) and propose a mathematical model for optimizing Web service composition regarding QoS. Additionally, a knowledge-driven differential evolution process is presented for optimizing Web service composition. By incorporating structural knowledge, this algorithm significantly enhances the convergence velocity. The research includes simulation experiments and an evaluation methodology, with results demonstrating that KDE (knowledge-based differential evolution) outperforms the PSO algorithm and original differential evolution for Web service composition.

Hosseinzadeh, et al. [21] have presented a novel integrated approach termed the Artificial Neural Network-based Particle Swarm Optimization (ANN-PSO) Algorithm, which is tailored to augment the Quality of Service (QoS) attributes within cloud-edge computing. The crux of their contribution lies in introducing a formal verification technique that employs labeled transition systems to evaluate crucial linear temporal logic equations systematically. This verification process bolsters the efficacy of candidate composite services and optimizes various QoS parameters within the context of the hybrid algorithm. The outcomes of the experiment exhibit the exceptional effectiveness of the proposed model, highlighted by its minimal verification time, low memory consumption, and capability to ensure critical specifications based on Linear Temporal Logic (LTL) formulas. Furthermore, they noted that the recommended model exceeds other service composition algorithms, attaining the ideal timing, reliability, and cost. Souri, et al. [22] introduced a hybrid formal verification approach to evaluate service composition in multi-cloud environments. The objective was to enhance the ultimate service configuration by reducing the number of cloud vendors involved while maintaining a high QoS. Their method involved a behavioral model to analyze request flow, selection of services, and combination within a varied cloud situation. The suggested procedure utilized model checking using Multi-Labeled Transition Systems (MLTS) and process algebra using Pi-Calculus to perform the analysis of service composition. These techniques were employed to monitor performance characteristics to measure the quality of service. The authors conducted experiments to validate the feasibility of their proposed approach, utilizing performance evaluations and confirmation setups. The experimental results demonstrated the effectiveness and viability of the approach in achieving optimized multi-cloud service composition with reliable QoS standards.

Wang and Liu [23] introduced an inventive approach by fusing the firefly optimization algorithm (FOA) with fuzzy logic, presenting a methodology adept at effectively harmonizing multiple QoS parameters while adhering to connectivity limitations in service composition. The crux of their contribution lies in the introduction of a novel metric, termed the model maturity metric, designed to assess the lifecycle of simulation models across various cloud scenarios. This study dynamically computes the maturity score for the amalgamated model, factoring in the collaborative relationships between model services. The authors further devised a new algorithm that integrates FOA and fuzzy logic to optimize and synthesize cloud model services. Empirical

findings underscored the efficacy of the proposed technique. It showcased a superior performance compared to previous methodologies in key aspects like energy consumption, availability, and response time. This substantiates the efficiency of the suggested approach in significantly enhancing the Quality of Service (QoS) within the realm of cloud service composition. Mohapatra, et al. [24] introduced a Multi-Criteria Decision-Making methodology that employs the Simple Additive Weighting (SAW) technique. This methodology assists customers in determining the preferable cloud service from a range of available services based on their individual satisfaction criteria.

Additionally, they proposed an enhanced approach called Eagle Strategy with Whale Optimization algorithm (ESWOA). This enhanced technique helps balance local and global optima, ensuring efficient optimization of cloud services. The system proposes time-saving, dependable, and trustworthy cloud services from the available pool by combining these methodologies. This recommendation system aids customers in finding the appropriate cloud services to satisfy their specific demands.

## III. PROBLEM STATEMENT

Service composition identifies the most suitable set of Cloud-based Services (CSs) from an array of available services to enhance user experience while adhering to QoS constraints. In Fig. 1, the formal definition of service composition is presented. It assumes that from a total of m candidate services available in the cloud, $n$ services ($X_1, X_2, \cdots, X_n$) must be combined to achieve the desired QoS and meet the user's requirements. There are various ways to combine a set of services, but evaluating all possible combinations and selecting the optimal method is time-consuming. This paper addresses the service combining issue using IAO. The system model for cloud service composition consists of several key components, including Cloud Providers (CPs), service requirements, QoS constraints, and types of composite service profiles. Different CP partners must collaborate and work together in a supply chain format to meet all service requirements. This collaboration allows them to leverage their unique strengths and capabilities, creating an optimal package of services that fulfills the customer's needs and ensures the highest QoS. Effective communication and coordination among CP partners are essential for a successful collaboration. CPs may offer multiple services, each involving one or more CPs. To meet the complex needs of customers, services from different commercial independent cloud platforms can be combined through mutual communication. This flexibility in combining services from various sources enhances the ability to satisfy customers' diverse and evolving requirements effectively.

In QoS-aware service composition, the cloud user initially provides a list of abstract services that describe the application requirements for a specific task. The cloud provider then composes these abstract services into a concrete and executable workflow, which is deployed within the cloud environment. The cloud provider considers the user's specified QoS constraints throughout this composition process, such as performance, reliability, and cost. These constraints play a crucial role in ensuring that the composed services meet the user's needs while optimizing the resulting workflow's cost, performance, and reliability. To achieve this optimization, the cloud provider evaluates and weighs the different QoS requirements against each other. By doing so, they can make informed decisions to select the most suitable composition of services that best aligns with the user's goals and fulfills the specified QoS constraints. Consider a set of n customer service requirements represented as $R = (R_1, R_2, ..., R_i, R_n)$ $(1 \leq i \leq n)$. Each abstract service $S_i$ $(1 \leq i \leq n)$ can satisfy a specific requirement $R_i$ in a particular order, adhering to the user's preferences and priorities for service composition. Cloud pools offer services catering to clients' diverse needs from numerous providers, aiming to boost their profitability. As client needs can be complex, they may require the compilation and orchestration of multiple services. Service composition aims to combine and organize these various services into a formalized workflow that efficiently processes client requests. Figure 2 illustrates the process of composing a cloud service, where n tasks represent the client's request. Each workflow task is matched with candidate services during service discovery. An optimization algorithm is employed to select the most suitable services to create a coherent path that fulfills the client's requirements.
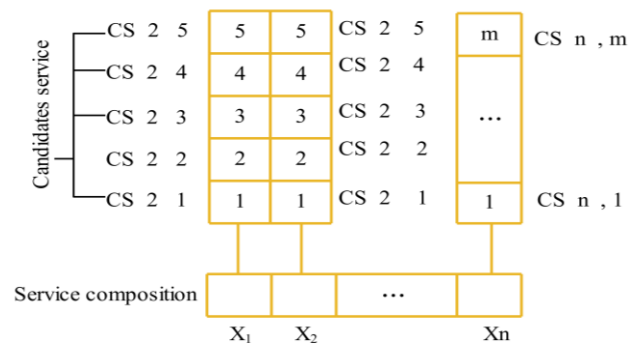


Fig. 1. Service composition model.

A workflow in this context represents a client request comprising n tasks and a list of $m$ candidate services. These workflows are represented using directed acyclic graphs (DAGs) with five tuples. $V = (T_1, T_2, ..., T_n)$ represents the workflow of n tasks, and each task includes a list of candidate services denoted as $(S_1^1, S_2^2, ..., S_n^m)$, where $S_i^j$ $(1 \leq i \leq n, 1 \leq j \leq m)$ represents the $j^{th}$ service for the $i^{th}$ task. An association between the services and QoS parameters is represented by $E$. The QoS parameters for the $j^{th}$ service are denoted as $(P_{1,i}^1, P_{2,i}^2, ..., P_{Q,n}^m$, where $P_{r,i}^j (1 \leq r \leq Q)$ represents the $r^{th}$ QoS parameter for the $j^{th}$ service. Here, $C$ represents the values of the QoS parameters, represented as $C = (C_1, C_2, ..., C_Q)$. The workflow patterns can be loop, conditional, parallel, or sequential, and they are denoted as $P$. $Q$ denotes the number of QoS parameters in the system. Furthermore, $W$ represents the clients' QoS desires, represented as $W = (W_1, W_2, ..., W_Q)$, indicating the specific values and priorities the clients require for the QoS parameters.

In the given formulation, there are multiple potential solutions in the form of infinite paths, with a total of less than

m solutions. However, the results obtained from optimization algorithms reveal that only one solution stands out as the best among all others. Hence, the service composition problem can be seen as a multi-objective optimization problem, as the goal is to find a single optimal solution. In the context of mobile cloud computing environments, the battery life of mobile devices is a critical factor. Therefore, three QoS factors, namely cost, response time, and energy, play a significant role in determining the optimal service composition. These QoS parameters are further divided into positive and negative factors. Positive factors, such as availability and throughput, are most beneficial to users when their values increase. On the other hand, negative factors, such as energy consumption and response time, benefit the user when their values are decreased. Optimization algorithms are employed to calculate the solution's fitness based on the following formula, which

considers the various QoS parameters and their effect on user satisfaction.

$$
\begin{aligned}
Fitness\ function &= W_1.Responsetime0 \\
&+ W_2.Energy + W_3.Cost
\end{aligned} \tag{1}
$$

In Eq. (1), the values of $W_1$, $W_2$, and $W_3$ are constrained to range from 0 to 1, and their sum is equal to 1. The proposed algorithm aims to select a composite service that yields the lowest fitness value. Table I illustrate the existing QoS factors, calculated using sum and product operations and then normalized to fall from 0 to 1. This normalization process ensures that all the QoS factors are on a comparable scale, allowing the algorithm to make a fair assessment and selection of the composite service with the most favorable QoS attributes.

TABLE I.        QOS AGGREGAATION FORMULAS AND WORKFLOW PATTERNS

| QoS parameter | Loop | Fork | Branch | Sequential |
|---|---|---|---|---|
| Cost | $\left(\prod_{i=1}^{n} C(a_i)\right)^k$ | $min_{i=1}^{P} C(s_i^f)$ | $\sum_{i=1}^{m} P_i.C(s_i^b)$ | $\prod_{i=1}^{m} C(a_i)$ |
| Energy consumption | $k.\sum_{i=1}^{n} E(a_i)$ | $max_{i=1}^{P} E(s_i^f)$ | $\sum_{i=1}^{m} P_i.E(s_i^b)$ | $\sum_{i=1}^{n} E(a_i)$ |
| Response time | $k.\sum_{i=1}^{n} T(a_i)$ | $max_{i=1}^{P} T(s_i^f)$ | $\sum_{i=1}^{m} P_i.T(s_i^b)$ | $\sum_{i=1}^{n} T(a_i)$ |

## IV. INTEGRATED AQUILA OPTIMIZER FOR SERVICE COMPOSITION

### A. Aquila Optimizer

The Aquila Optimization (AO) algorithm draws inspiration from the hunting behaviors of the Aquila (eagle) during its pursuit of prey. The hunting process involves four steps: expanded exploration, narrowed exploration, expanded exploitation, and narrowed exploitation. To transition from the exploration stage to the exploitation stage, the AO algorithm incorporates various behaviors. In the initial two-thirds of iterations, the algorithm replicates the exploration phase, followed by the emulation of the exploitation phase in the concluding one-third of iterations. Mathematically, the AO algorithm can be described as follows:

Initializing: A total of *N* solutions are strategically distributed within a D-dimensional exploration domain, delimited by a predetermined range denoted as *[L, U]*. This allocation is accomplished through the utilization of Eq. (2), where $X_{i,j}$ denotes the value in the $j^{th}$ dimension of the $i^{th}$ solution. Here, $L_j$ and $U_j$ signify the lower and upper boundary values pertaining to the $j^{th}$ dimension within the exploration space, while $r$ signifies a randomly generated value within the range of 0 to 1. The spatial coordinates of these solutions are meticulously recorded in a matrix denoted as $X_{N \times D}$. Subsequently, the fitness value for each individual solution is computed through the function $f(X_i)$.

$$X_{i,j} = L_j + r \times (U_j - L_j) \tag{2}$$

Expanded exploration: An Aquila, or eagle, employs a distinct strategy for locating potential prey by identifying regions of interest and strategically selecting optimal hunting locations through a combination of high soaring and vertical stooping. This behavior enables the bird to survey the search area from elevated vantage points, aiding in the estimation of potential prey locations. The AO algorithm simulates this approach to expand exploration, as captured by Eq. (3). This simulation occurs when the ongoing iteration count is less than two-thirds of the total maximum iterations, and a randomly generated value falls below 0.5. Within Eq. (3), $X_1(iter + 1)$ corresponds to the solution generated from the prime method, intended for utilization in the subsequent iteration. $X_{best}(iter)$ designates the best solution discovered up to the current iteration, serving as an approximation of the prey's position. The term $(1 - \frac{iter}{MaxIter})$ is employed to regulate the extent of exploration based on the progression of iterations. Here, *iter* denotes the current iteration count, and *MaxIter* represents the total number of iterations. In the $iter^{th}$ iteration, $X_M(iter)$ represents the mean of the presently available solutions, computed using Eq. (4). This mean value acts as a guide for the exploration process, providing a directional influence for the algorithm as it navigates the search space in pursuit of the optimal solution.

$$
\begin{aligned}
X_1(iter + 1) = X_{best}(iter) \times \left(1 - \frac{iter}{MaxIter}\right) \\
+ (X_M(iter) - X_{best}(iter) \times r)
\end{aligned} \tag{3}
$$

$$X_M(iter) = \frac{1}{N}\sum_{i=1}^{N} X_i(iter), \forall j = 1,2,\dots,D \tag{4}$$

In Eq. (4), the variable $N$ denotes the total number of solutions within the population, while $D$ signifies the dimensionality of the search space.

Narrowed exploration: The hunting behavior of the Aquila, referred to as "contour flight" or "short glide attack," involves the bird hovering over its intended prey, descending swiftly upon spotting the prey from an elevated position. This tactic allows the Aquila to explore a designated region with precision thoroughly. The AO algorithm emulates this focused exploration strategy through Eq. (5), enacted when the ongoing iteration count remains less than two-thirds of the maximum iterations and a randomly generated value exceeds 0.5. In Eq. (5), $X_2(iter + 1)$ represents the solution generated by the narrowed exploration technique. $X_R(iter)$ denotes a solution randomly selected from the entire set of solutions during the iter-th iteration.

Additionally, *Levy(D)* signifies the Levy flight distribution function, calculated via Eq. (6). The Levy flight distribution function, as defined in Eq. (6), exerts an influence on the movement of solutions during the narrowed exploration phase. By introducing controlled random deviations, this distribution facilitates dynamic and efficient exploration of the search space. This stochastic behavior enables the algorithm to focus on specific areas of interest during the narrowed exploration phase, potentially leading to the discovery of promising solutions.

$$X_2(iter + 1) = X_{best}(iter) \times Levy(D) + X_R(iter) \\ + (y - x) \times r \tag{5}$$

$$Levy(D) = s \times \frac{u \times \sigma}{|v|^{\frac{1}{\beta}}}, \sigma = \left(\frac{\Gamma(1 + \beta) \times \sin(\frac{\pi\beta}{2})}{\Gamma(\frac{1 + \beta}{2}) \times \beta \times 2^{(\frac{\beta-1}{2})}}\right) \tag{6}$$

Eq. (6) delineates the parameter values as follows: $\beta = 1.5$ and $s = 0.01$. In addition, the variables $u$ and $v$ are integer values randomly generated within the range of 0 to 1. Moving to Eq. (5), the spiral pattern is depicted through the variables $y$ and $x$, which are computed using Eq. (7). Eq. (7) relies on the calculations of the variables $r$ and $\theta$. The value of $r$ is established using Eq. (8), while the value of $\theta$ is computed through Eq. (9). In Eq. (8) and Eq. (9), the number of search cycles is determined by the random number $r_1$, which assumes values between 1 and 20. $D_1$ denotes an integer value ranging from 1 to $D$, where $D$ signifies the dimensionality of the search space. $U$ is a constant set to 0.0056, and $\omega$ is another constant established at 0.005. These parameters collectively contribute to the computation of the spiral form in Eq. (7), playing a pivotal role in shaping the movement and exploration patterns of solutions during the narrowed exploration phase within the framework of the AO algorithm.

$$y = p \times \cos(\theta), x = p \times \sin(\theta) \tag{7}$$

$$p = r_1 + U \times D_1 \tag{8}$$

$$\theta = -\omega \times D_1 + \theta_1, \theta_1 = \frac{3 \times \pi}{2} \tag{9}$$

Expanded exploitation: Aquila adopts the "low-flying descent attack" tactic to capture its target in the expanded exploitation phase. After carefully identifying the prey zone, the Aquila prepares to descend and attack. It descends vertically and executes the first strike to gauge how the prey would respond. The AO algorithm simulates this low-flying descent attack behavior using Eq. (10). It is performed when the current iteration is greater than two-thirds of the maximum iterations and a randomly generated value is less than 0.5. Eq. (10) introduces $X_3(iter + 1)$ as the solutions generated through the expanded exploitation approach. The parameters governing exploitation adjustment, $\alpha$ and $\delta$, are both fixed at a value of 0.1. These parameters play a role in fine-tuning the exploration and exploitation balance during the expanded exploitation stage. The values of $\alpha$ and $\delta$ help control the level of exploitation, influencing how the algorithm explores the promising regions discovered earlier and refines the solutions to find the optimal solution more effectively.

$$X_3(iter + 1) = \left(X_{best}(iter) - X_M(iter)\right) \times \alpha - r \\ + ((U - L) \times r + L) \times \delta \tag{10}$$

Narrowed exploitation: In the narrower exploitation phase, the Aquila adopts a "walking and grabbing the prey" strategy, characterized by a randomized approach towards the prey followed by an attack. This action is executed when the current iteration is greater than two-thirds of the maximum iterations and a randomly generated value is greater than 0.5. This behavior is simulated using Eq. (11). In Eq. (11), $X_4(iter + 1)$ signifies the fourth search solution generated, $X(iter)$ denotes the current solution during the $iter^{th}$ iteration, and a quality function referred to as $QF$ is computed using Eq. (12) to regulate and balance the search strategy. To determine the values of $G_1$ and $G_2$, which represent the Aquila's prey tracking movements, Eq. (13) and Eq. (14) are utilized.

$$X_4(iter + 1) = QF(iter) \times X_{best}(iter) \\ - (G_1 \times X(iter) \times r) - G_2 \\ \times Levy(D) + r \times G_1 \tag{11}$$

$$QF(iter) = t^{\frac{2 \times r - 1}{(1 - MaxIter)^2}} \tag{12}$$

$$G_1 = 2 \times r - 1 \tag{13}$$

$$G_2 = 2 \times (1 - \frac{iter}{MaxIter}) \tag{14}$$

### B. Particle Swarm Optimization

PSO is an intelligent, biologically inspired algorithm that draws its origins from the study of avian predatory behavior. At its core, PSO operates on the principle of identifying optimal solutions through collaborative interaction and the exchange of information among individual members within a group. In PSO, each individual is represented as a bird, and their positions and speeds are treated as independent variables. The objective function value at each location is related to the food density, and the goal is to find the optimal location with the highest food density, which corresponds to the optimal solution to the problem. Each bird adjusts its search direction and speed based on the difference between its historical best position and the best position found by the entire population. By continuously updating their positions and speeds and sharing information with each other, the bird swarm gradually

converges toward the optimal population location. This collective effort leads to finding the optimal solution called problem convergence.

Within the realm of optimization, the PSO algorithm is often conceptualized as a stochastic search challenge occurring in a D-dimensional space. The central aim is to optimize a given objective function. In this D-dimensional environment, a population of *n* particles are denoted as $p_i = (p_{i1}, p_{i2}, ..., p_{iD})^T$, where each $i^{th}$ particle is composed of a d-dimensional position vector $x_i = (x_{i1}, x_{i2}, ..., x_{id})^T$ and a velocity vector $v_i = (v_{i1}, v_{i2}, ..., v_{id})T$. The PSO algorithm commences with each particle initiating its search within the D-dimensional space, leveraging an initial set of randomized particles. Through a series of iterative updates, the particle embarks on a quest to identify an optimal solution. During this continuous exploration, the particle maintains its present optimal position, $p_i = (p_{i1}, p_{i2}, ..., p_{id})^T$, representing its local optimum, and its velocity $v_i = (v_{i1}, v_{i2}, ..., v_{id})^T$. The global optimal solution, $p_g = (p_{g1}, p_{g2}, ..., p_{gd})T$, signifies the finest solution collectively discovered by the entire particle swarm during optimization. In each iteration, the particle refines its position and velocity by considering two distinct "optimal solutions": its local best position and the global best position. By updating its position and velocity using the specified equations outlined in Eq. (15) and Eq. (16), the particle navigates towards its local best position while being influenced by the superior global best position identified by the swarm as a whole. The PSO algorithm recurrently applies these updates, fostering the gradual convergence of particles towards the global optimal solution. This iterative process orchestrates the collective efforts of particles, ultimately yielding optimization of the objective function and culminating in the discovery of the paramount solution for the given optimization quandary.

$$v_{id}(t + 1) = \omega v_{id}(t) + c_1 r_1 \big(p_{id}(t) - x_{id}(t)\big) + c_2 r_2 \big(p_{gd}(t) - x_{id}(t)\big) \tag{15}$$

$$x_{id}(t + 1) = x(t) + v_{id}(t + 1), \quad i = 1,2,...,N; d = 1,2,...,D \tag{16}$$

### C. Proposed IAO Algorithm

The IAO incorporates two main search methods, namely the Aquila Optimizer and Particle Swarm Optimizer, to enhance its search capabilities. A novel transition mechanism (TM) is employed to balance the search process and preserve the diversity of solutions. This transition mechanism, as shown in Eq. (17), aims to prevent the algorithm from getting trapped in local optima and improve the quality of the candidate solutions. By combining the strengths of both the Aquila Optimizer and Particle Swarm Optimizer and using the transition mechanism, the proposed IAO method aims to achieve more robust and efficient optimization performance.

$$TM = \frac{1}{2} Sin \left( \pi + 2\pi \times \frac{t}{T} \right) + rand \tag{17}$$
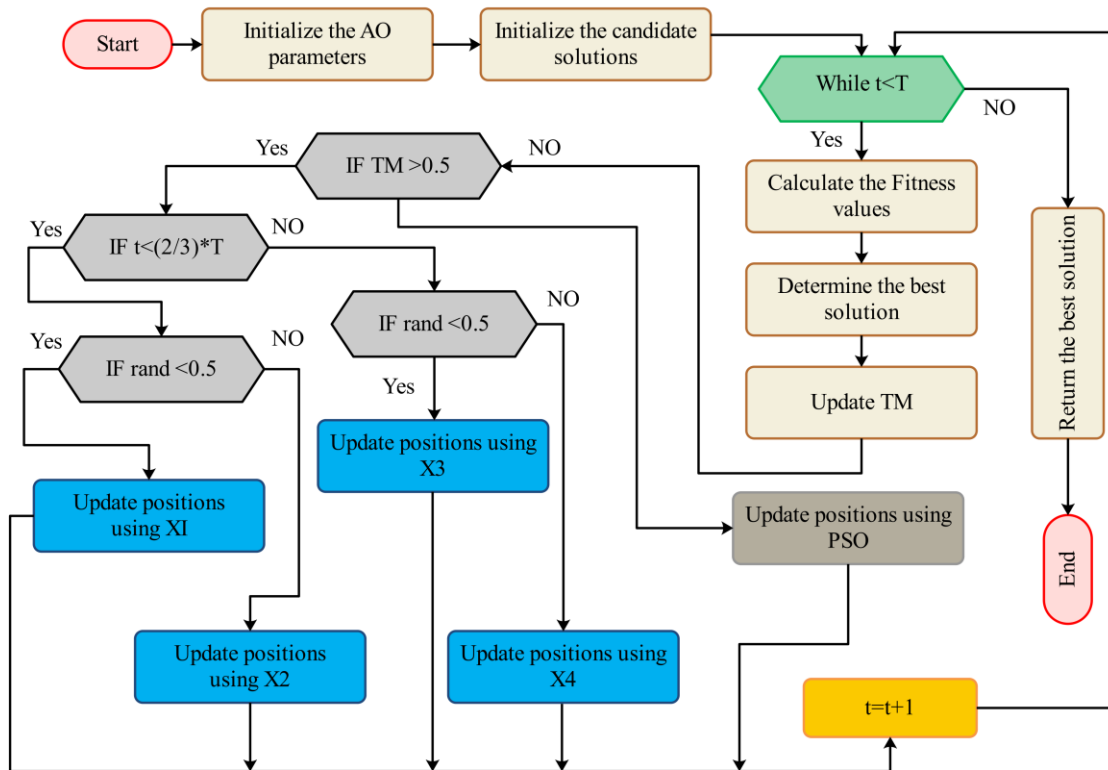


Fig. 2. The flowchart of the proposed method.

Fig. 2 illustrates the general procedure of the proposed IAO method. The method begins by initializing the solutions and defining the required parameters, including the transition parameter (TM). The TM is crucial in determining the

optimization process used in each iteration. During the optimization process, if the value of the TM is greater than the current iteration number (t), the algorithm utilizes the Aquila Optimizer's operators for updating the solutions. On the other hand, if the TM is less than or equal to the current iteration number (t), the Particle Swarm Optimizer's operators are employed for updating the solutions. By dynamically switching between the two search methods based on the TM, the proposed IAO method enhances the diversity of the solutions. It avoids getting trapped in specific search areas, especially local search areas. This approach allows the algorithm to balance exploration and exploitation effectively, leading to improved overall performance and better convergence toward the optimal solution.

## V. SIMULATION

To assess the superiority of the IAO method in solving large-scale cloud service composition problems, its performance is compared with several other algorithms: Genetic Algorithm (GA), Max-Min Ant System (MMAS), Artificial Bee Colony (ABC), and PSO. The comparison is conducted using two large-scale problems denoted by the task scale *T(n, m)*, where *n* represents the number of subtasks equal to 30, *m* represents the number of candidate services for each subtask, with $m \in \{100, 300\}$. For instance, *T(30, 300)* indicates 30 subtasks and 300 candidate services. In this comparison, the QoS evaluation index is normalized.

Fig. 3 and Fig. 4 present the box plots of the average QoS fitness values obtained from the experimental data for each cloud service composition problem scale. These box plots allow for a visual comparison of the performance of different algorithms, showcasing the distribution and variation in their average fitness values. Fig. 5 shows the average time consumption for each algorithm during the experiment. Based on the computational results, it is evident that the IAO method outperforms the other algorithms regarding the maximum fitness values obtained. In the *T (30, 100)* problems, the

maximum values in all five algorithms are relatively similar. However, as the scale of the problem increases, a noticeable gap starts to emerge between IAO and the other algorithms. IAO consistently performs at the top, GA and PSO at the bottom, and MMAS and ABC in the middle. The IAO method demonstrates faster optimization time compared to MMAS as the scale of the problem increases. This advantage becomes more pronounced for larger and more complex cloud service composition problems. IAO's faster optimization lies in its incorporation of GA to optimize the solutions generated by the ant colony algorithm. By combining these two optimization techniques, IAO can dynamically adjust and fine-tune the solutions, fully leveraging the strengths of the genetic algorithm.

The stability of the optimal solution is indeed superior in both IAO and MMAS compared to other algorithms, such as GA and PSO. The key reason behind this enhanced stability is that IAO and MMAS are designed to effectively avoid local optima during optimization. Ant-colony algorithms, including MMAS, utilize pheromone-based communication and exploration, which allows them to strike a balance between exploitation and exploration. This helps prevent premature convergence to local optima and encourages the algorithm to explore a more diverse and promising search space. On the other hand, GA and PSO are more prone to premature convergence, especially in complex optimization problems. This can lead to less stable solutions as they might get trapped in local optima, failing to explore other potential regions of the search space. It is evident from the results that IAO outperforms the other algorithms in terms of accuracy, especially as the scale of the problem increases. The higher accuracy achieved by IAO can be attributed to the strengths of the ant algorithm in searching large spaces. The AO is particularly well-suited for exploring complex and vast search spaces, as it leverages pheromone-based communication and dynamic adjustments to navigate the problem domain efficiently.
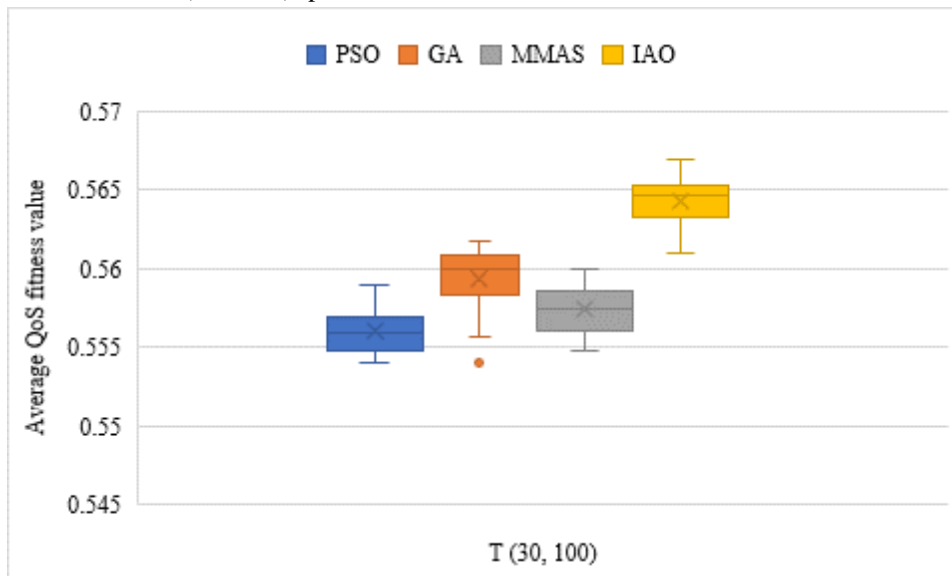


Fig. 3. Box plot of the optimal solution for 100 candidate services.
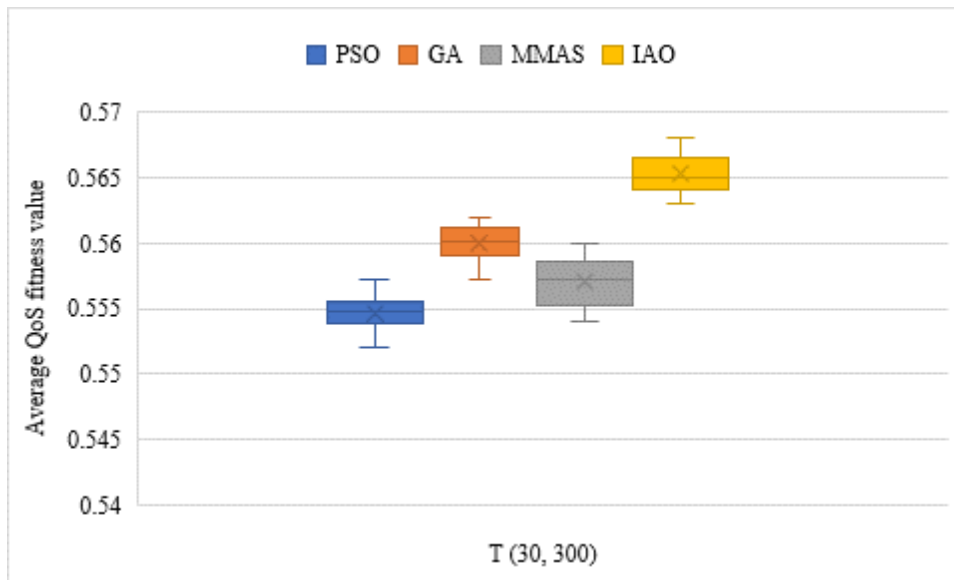
Fig. 4. Box plot of the optimal solution for 300 candidate services.
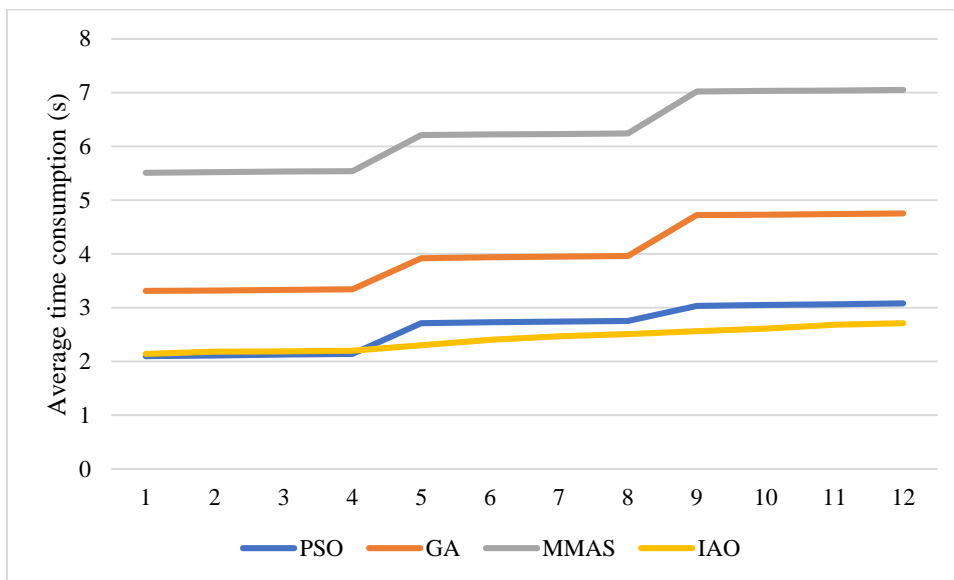


Fig. 5. Time consumption comparison.

Additionally, the iterative adjustment threshold and increased ant population size introduced in the IAO algorithm contribute to its improved accuracy. These modifications help fine-tune the search process and facilitate more thorough exploration, which enables IAOs to find high-quality solutions more effectively. As the scale of the problem grows, the advantage of IAO becomes more pronounced, as it can consistently deliver more accurate solutions compared to other algorithms like MMAS and GA. This demonstrates the capability of IAO as a robust and accurate optimization method, making it a promising choice for tackling large-scale cloud service composition problems and other complex optimization challenges.

## VI. CONCLUSION

Cloud computing has gained immense popularity due to its numerous benefits, such as cost-effectiveness and the ability to offer a wide range of hardware and software services. However, composing different services to fulfill complex requests poses challenging Np-hard problems. To overcome this, service composition becomes essential for creating more extensive services with enhanced functionalities. This paper introduced a novel hybrid method called IAO, which combines the strengths of both the conventional AO and PSO algorithms. By combining AO and PSO, this hybridization aims to address their weaknesses, such as low solution diversity and being trapped in local search. To tackle these challenges, the proposed IAO method incorporates a unique transition mechanism that enables seamless changes between search operators. This mechanism allows the algorithm to switch between AO and PSO when necessary, especially when either algorithm gets stuck, or the diversity of solutions declines. This adaptability enhances the overall performance and effectiveness of the hybrid approach. The performance of the

IAO method is extensively tested through experiments on the Cloudsim simulation platform. Comparative experiments are conducted, and the results demonstrate that IAO significantly improves the accuracy and stability of large-scale cloud service composition problems. Moreover, the time consumption of the algorithm is also optimized, showcasing its efficiency in solving complex optimization problems.

In future research, this work can be extended in several directions. First, a deeper exploration of the scalability and adaptability of the IAO in larger, more complex cloud environments could offer valuable insights. Additionally, investigating the integration of IAO with emerging technologies like edge computing or hybrid cloud setups could enhance its applicability across diverse computing landscapes. Further research could refine the transition mechanism of IAO to dynamically adapt to changing network conditions and varying service demands in real-time. Moreover, exploring the impact of IAO in multi-objective optimization scenarios to simultaneously optimize conflicting QoS metrics would be a compelling avenue for advancement. Lastly, a thorough investigation into the security implications and resilience of IAO against potential attacks or failures within cloud environments could be a pivotal direction for future improvement.

REFERENCES

[1] B. Pourghebleh, A. A. Anvigh, A. R. Ramtin, and B. Mohammadi, "The importance of nature-inspired meta-heuristic algorithms for solving virtual machine consolidation problem in cloud environments," Cluster Computing, pp. 1-24, 2021.

[2] P. Bakaraniya, S. Patel, and P. Singh, "5G Enabled Smart City Using Cloud Environment," in Predictive Analytics in Cloud, Fog, and Edge Computing: Perspectives and Practices of Blockchain, IoT, and 5G: Springer, 2022, pp. 199-226.

[3] K. Prasanna Kumar and K. Kousalya, "Amelioration of task scheduling in cloud computing using crow search algorithm," Neural Computing and Applications, vol. 32, no. 10, pp. 5901-5907, 2020.

[4] K. K. Gola, B. M. Singh, B. Gupta, N. Chaurasia, and S. Arya, "Multi-objective hybrid capuchin search with genetic algorithm based hierarchical resource allocation scheme with clustering model in cloud computing environment," Concurrency and Computation: Practice and Experience, vol. 35, no. 7, p. e7606, 2023.

[5] V. Hayyolalam, B. Pourghebleh, and A. A. Pourhaji Kazem, "Trust management of services (TMoS): Investigating the current mechanisms," Transactions on Emerging Telecommunications Technologies, vol. 31, no. 10, p. e4063, 2020.

[6] V. Hayyolalam, B. Pourghebleh, M. R. Chehrehzad, and A. A. Pourhaji Kazem, "Single-objective service composition methods in cloud manufacturing systems: Recent techniques, classification, and future trends," Concurrency and Computation: Practice and Experience, vol. 34, no. 5, p. e6698, 2022.

[7] P. Behrouz, H. Vahideh, and A. A. Aghaei, "Service discovery in the Internet of Things: review of current trends and research challenges," Wireless Networks, vol. 26, no. 7, pp. 5371-5391, 2020.

[8] H. Vahideh, P. Behrouz, P. K. A. Asghar, and A. Ghaffari, "Exploring the state-of-the-art service composition approaches in cloud manufacturing systems to enhance upcoming techniques," The International Journal of Advanced Manufacturing Technology, vol. 105, no. 1-4, pp. 471-498, 2019.

[9] B. Pourghebleh and V. Hayyolalam, "A comprehensive and systematic review of the load balancing mechanisms in the Internet of Things," Cluster Computing, pp. 1-21, 2019.

[10] P. He, N. Almasifar, A. Mehbodniya, D. Javaheri, and J. L. Webber, "Towards green smart cities using Internet of Things and optimization algorithms: A systematic and bibliometric review," Sustainable Computing: Informatics and Systems, vol. 36, p. 100822, 2022, doi: https://doi.org/10.1016/j.suscom.2022.100822.

[11] S. Habib, S. Aghakhani, M. G. Nejati, M. Azimian, Y. Jia, and E. M. Ahmed, "Energy management of an intelligent parking lot equipped with hydrogen storage systems and renewable energy sources using the stochastic p-robust optimization approach," Energy, p. 127844, 2023.

[12] R. Singh et al., "Analysis of Network Slicing for Management of 5G Networks Using Machine Learning Techniques," Wireless Communications and Mobile Computing, vol. 2022, 2022.

[13] S. N. H. Bukhari, J. Webber, and A. Mehbodniya, "Decision tree based ensemble machine learning model for the prediction of Zika virus T-cell epitopes as potential vaccine candidates," Scientific Reports, vol. 12, no. 1, p. 7810, 2022.

[14] B. M. Jafari, M. Zhao, and A. Jafari, "Rumi: An Intelligent Agent Enhancing Learning Management Systems Using Machine Learning Techniques," Journal of Software Engineering and Applications, vol. 15, no. 9, pp. 325-343, 2022.

[15] T. Gera, J. Singh, A. Mehbodniya, J. L. Webber, M. Shabaz, and D. Thakur, "Dominant feature selection and machine learning-based hybrid approach to analyze android ransomware," Security and Communication Networks, vol. 2021, pp. 1-22, 2021.

[16] J. Webber, A. Mehbodniya, Y. Hou, K. Yano, and T. Kumagai, "Study on idle slot availability prediction for WLAN using a probabilistic neural network," in 2017 23rd Asia-Pacific Conference on Communications (APCC), 2017: IEEE, pp. 1-6.

[17] M. Sadi et al., "Special Session: On the Reliability of Conventional and Quantum Neural Network Hardware," in 2022 IEEE 40th VLSI Test Symposium (VTS), 2022: IEEE, pp. 1-12.

[18] S. Mahmoudinazlou, A. Alizadeh, J. Noble, and S. Eslamdoust, "An improved hybrid ICA-SA metaheuristic for order acceptance and scheduling with time windows and sequence-dependent setup times," Neural Computing and Applications, pp. 1-19, 2023.

[19] L. Bao et al., "An evolutionary multitasking algorithm for cloud computing service composition," in Services–SERVICES 2018: 14th World Congress, Held as Part of the Services Conference Federation, SCF 2018, Seattle, WA, USA, June 25–30, 2018, Proceedings 14, 2018: Springer, pp. 130-144.

[20] J. Qi, B. Xu, Y. Xue, K. Wang, and Y. Sun, "Knowledge based differential evolution for cloud computing service composition," Journal of Ambient Intelligence and Humanized Computing, vol. 9, pp. 565-574, 2018.

[21] M. Hosseinzadeh et al., "A Hybrid Service Selection and Composition Model for Cloud-Edge Computing in the Internet of Things," IEEE Access, vol. 8, pp. 85939-85949, 2020.

[22] A. Souri, A. M. Rahmani, N. J. Navimipour, and R. Rezaei, "A hybrid formal verification approach for QoS-aware multi-cloud service composition," Cluster Computing, vol. 23, pp. 2453-2470, 2020.

[23] W. Wang and Z. Liu, "Cloud Service Composition using Firefly Optimization Algorithm and Fuzzy Logic," International Journal of Advanced Computer Science and Applications, vol. 14, no. 3, 2023.

[24] S. S. Mohapatra, R. R. Kumar, and J. Pradhan, "Hybrid eagle strategy for QOS-based cloud service composition," Journal of Information and Optimization Sciences, vol. 43, no. 5, pp. 1047-1059, 2022.

# QoS and Energy-aware Resource Allocation in Cloud Computing Data Centers using Particle Swarm Optimization Algorithm and Fuzzy Logic System

Yu Wang[1*], Lin Zhu[2]

School of Computer Science, Xi'an Aeronautical Institute, Xi'an, Shaanxi, 710077, China[1]
Motorcycle Test Technology Institute of China South Industries Group Corporation[2]
Xi'an, Shaanxi, 710032, China[2]

*Abstract*—**Cloud computing has become a viable option for many organizations due to its flexibility and scalability in providing virtualized resources via the Internet. It offers the possibility of hosting pervasive applications in the consumer, scientific, and business domains utilizing a pay-as-you-go model. This makes cloud computing a cost-effective solution for businesses as it eliminates the need for large investments in hardware and software infrastructure. Furthermore, cloud computing enables organizations to quickly and easily scale their services to meet the demands of their customers. Resource allocation is a major challenge in cloud computing. It is known as the NP-hard problem and can be solved using meth-heuristic algorithms. This study optimizes resource allocation using the Particle Swarm Optimization (PSO) algorithm and fuzzy logic system developed under the proposed time and cost models in the cloud computing environment. Receiving, processing, and waiting time are included in the time model. The cost model incorporates processing and receiving costs. Two experiments demonstrate the performance of the proposed algorithm. The simulation results demonstrate the potential of our mechanism, demonstrating improved performance over previous approaches in aspects such as providers' total income, users' total revenue, resource utilization, and energy consumption.**

*Keywords—Cloud computing; resource allocation; scheduling; PSO; fuzzy logic*

## I. INTRODUCTION

Cloud computing offers on-demand access to various computing resources, including software, platforms, and storage [1]. Coupled with IoT and big data applications, it has revolutionized information technology operations, becoming the enabling technology for next-generation communications [2]. Energy consumption is a significant challenge for cloud data centers, given the substantial and constantly evolving size of cloud computing infrastructures and the rapidly growing number of users [3]. From 2005 to 2010, there has been an average annual increase of 12% in energy consumption, which has intensified over the past few years [4]. Excessive energy consumption produces excessive heat emissions and increases costs, resulting in a degradation of system reliability and performance [5]. As energy costs rise and availability diminishes, data center resource management should be optimized for energy efficiency while ensuring high service levels [6]. Consequently, cloud service providers must guarantee that rising energy costs do not adversely affect their profit margins. Rising energy costs seriously threaten cloud infrastructures as they increase the Total Cost of Ownership (TCO) and reduce the Return on Investment (ROI) [7].

Energy efficiency in data centers is a complex problem since computing applications and data grow rapidly, and larger servers and disks are required to meet the processing times [8]. Green cloud computing aims to optimize the processing and management of computing infrastructure while reducing energy consumption [9]. The success of cloud computing depends on the sustainability of its future growth. The advent of cloud computing with increasingly pervasive frontend client devices interacting with backend data centers could cause energy consumption to skyrocket [10]. To promote green cloud computing, data centers should be operated efficiently. Cloud resources should be allocated according to user-specified Quality of Service (QoS) criteria via Service Level Agreements (SLAs) and minimize energy consumption. Multiple subscribers are served by combining the resources in the cloud [11]. Using a multi-tenancy model, the provider dynamically multiplexes the resources (physical and virtual) according to the requirements of each tenant [12]. Based on the lease and SLA agreement, the number of virtual resources will be assigned based on the needs of each client. As a result, as cloud service demand has grown, providers have had to scale up the number of resources and capabilities of cloud-based services to handle the increasing resource demands [13]. Fig. 1 shows a process for allocating resources in a cloud environment.

Integrating Internet of Things (IoT), machine learning, deep learning, and neural networks within cloud resource allocation marks a transformative shift in addressing the complexities of modern computing landscapes [14]. The IoT introduces a vast network of interconnected devices and sensors, generating copious data streams requiring efficient processing and resource allocation [15, 16]. Machine learning, especially when combined with deep learning and neural networks, enables cloud systems to learn, adapt, and make data-driven decisions, facilitating predictive analytics for demand forecasting and user behavior analysis [17, 18]. These technologies empower cloud resource allocation mechanisms by automating decision-making processes, optimizing resource distribution, and enhancing the scalability of computing systems [19]. Neural networks, a subset of deep learning, allow for pattern recognition, predictive modeling, and intelligent decision-

making, ensuring more accurate and adaptive resource allocation strategies [20, 21]. Leveraging IoT data and machine learning capabilities within cloud resource allocation not only enhances system efficiency but also allows for dynamic adjustments, adaptive resource scaling, and predictive provisioning, ultimately leading to improved QoS and streamlined cloud operations in a rapidly evolving technological landscape [22].

The significance of meta-heuristic algorithms in cloud resource allocation lies in their capacity to efficiently navigate cloud environments' complex, dynamic, and constantly evolving landscape, offering optimized solutions amidst varying user demands and operational challenges. This paper introduces a hybrid optimization algorithm to address the issues in multi-cloud resource allocation. Particle Swarm Optimization (PSO) algorithm and fuzzy logic system are combined as a hybrid approach to reduce the problems in multi-cloud resource allocation. The selected optimization algorithms are known for their optimal global solutions and rapid convergence characteristics. While PSO exhibits robust optimization capabilities, the integration of fuzzy logic manages the uncertainties and imprecisions inherent in the dynamic nature of cloud environments. Fuzzy logic enhances the adaptability and robustness of decision-making, particularly

in scenarios involving vague or uncertain data, thereby augmenting resource allocation's overall accuracy and effectiveness. This combined approach prioritizes QoS criteria and energy efficiency in cloud data center resource allocation. The principal contributions of this paper can be summarized as follows:

- Combining the PSO algorithm and fuzzy logic system for solving the resource allocation problem in cloud computing.

- Enhancing resource utilization and reducing the execution time of the resource allocation problem.

- Increasing user and provider utility and reducing the generational distance of the resource allocation problem.

This paper presents an efficient resource allocation model that takes advantage of the benefits of optimization algorithms. The remainder of the paper is organized in the following manner. Section II reviews the previous cloud resource allocation approaches. Section III describes the proposed cloud resource allocation mechanism. Experimental results are reported in Section IV. Section V concludes the paper.
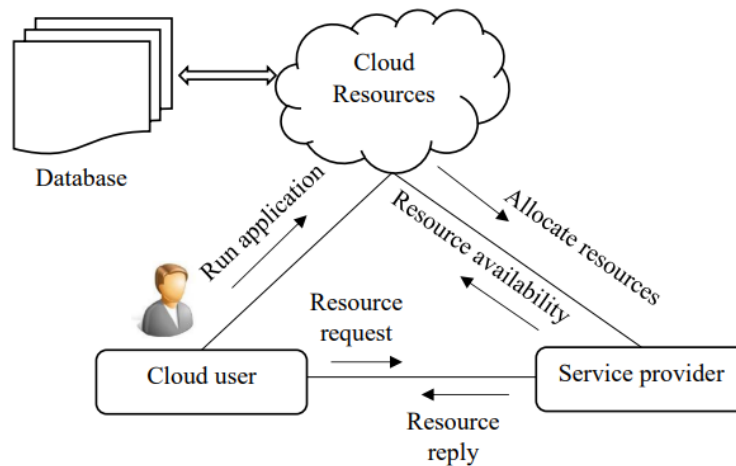


Fig. 1. Cloud resource allocation process.

## II. RELATED WORK

Wang and Su [23] developed an algorithm for dynamically allocating resources among numerous cloud nodes operating in a big data context. Based on computing power and storage factors, this algorithm uses fuzzy pattern recognition to divide nodes and tasks into distinct levels. Therefore, a dynamic mapping between tasks and nodes is generated. Upon the arrival of a new task, only the nodes corresponding to the task level will join the bid. The algorithm uses a hierarchical approach to minimize communication traffic during resource allocation. Based on the results of experiments, the presented algorithm is more efficient regarding makes span and communication traffic than the Min-Min algorithm.

The cloud-based disassembly proposed by Jiang, et al. [24] abstracts the disassembly factory as a disassembly resource, allowing it to be allocated to disassembly tasks. Based on this

model, a cloud-based disassembly solution is developed that offers users a disassembly service tailored to their needs. Disassembly services are execution plans for tasks derived from scheduling and allocating disassembly tasks. The paper uses a mathematical model to describe the disassembly service formally by taking into account the uncertainty associated with disassembly processes and the precedence relationships between tasks involved.

Mousavi, et al. [25] presented a hybrid approach to load balancing that integrates Grey Wolves Optimization (GWO) and Teaching-Learning-Based Optimization (TLBO) algorithms, aiming to maximize throughput by balancing virtual machine loads and avoiding a local optimum trap. The algorithm is evaluated on eleven benchmark functions, and comparisons are made with particle swarm optimization (PSO), biogeography-based optimization (BBO), and GWO.

Cloud computing is characterized by elasticity, distinguishing it from other paradigms, such as cluster and grid computing. Based on the bio-inspired coral-reef optimization paradigm, Ficco, et al. [26] developed a meta-heuristic approach to cloud resource allocation. The resource reallocation schema was optimized using classic Game Theory based on cloud provider optimization objectives and customer requirements expressed through fuzzy linguistic SLAs.

Chen, et al. [27] presented a self-adapting resource allocation methodology that consists of several feedback loops, each involving a PSO-based runtime decision algorithm and an iterative QoS prediction model. Each iteration of the algorithm improves QoS values. Future resource allocation operations are determined based on the predicted QoS value and the PSO-based runtime decision algorithm. As the PSO-based algorithm iterates, no further improvements are suggested compared to current resource allocations. The proposed method is evaluated on the RUBiS benchmark, highlighting a 20% improvement in QoS prediction accuracy compared to the current state of the art based on the same historical data.

Singhal and Singhal [28] developed a Feedback-based Combinatorial Fair Economical Double Auction Resource Allocation Model (FCFEDARA) to determine provider genuineness based on the prices offered and feedback from customers. The proposed framework enables customers to access resources from different providers at the best prices and prioritizes genuine providers with good feedback over non-genuine providers with bad reviews. Providers and customers submit bundle bids and resource lists in the combinatorial double auction model. By assessing provider truthfulness, penalizing market spoilers, and giving preference to providers with positive feedback from customers, the proposed model takes care of the truthfulness of providers.

Thakur and Goraya [29] introduced a novel metaheuristic-based resource allocation approach for load balancing in cloud environments. The goal is to effectively reduce the uneven distribution of workloads between physical machines in addition to their resource capabilities. Consequently, the over- or under-loading of active physical machines is prevented. To develop a suitable resource allocation strategy for load balancing, dragonfly and PSO algorithms are combined. The proposed algorithm is superior to PSO, dragonfly algorithm, and comprehensive learning PSO in determining optimal resource allocation.

## III. PROPOSED METHOD

A new PSO algorithm is used in this paper to select the best member of the population. This algorithm outperforms existing multi-objective optimization techniques regarding calculation time, reasonable undefeated solutions distribution, and Pareto front convergence. Moreover, the Fuzzy set theory is used in this paper to select the best adaptive solution.

### A. Mathematical Formulation of the Problem

Each user requests a combination of the requested resources with different attributes, the required number of the resources, and a proposed cost to buy all the resources in a bundle form. Each provider presents a combination of the resources with different attributes, the number of the presented

resources, and a proposed cost to sell all the resources in a bundle form. The bundle is a request to buy with all bought products and a sell request with all products. Moreover, the meaning of a specific attribute of the requested items is the number showing the processor processing power, the accumulator capacity, bandwidth, and so on. The total number of requested resources should equal or less than the total number of all the presented resources. All the users requested resources' attributes should be equal to or less than all the presented attributes by the cloud presenter to assign the resources. After determining which provider can meet the user's requests, the cost that the user should pay to the provider is determined by a costing model. The costing model should be fair and beneficial for the provider and the user. The costing model used in this paper is the presented method in [30] and [31]. Table I lists the symbols and variables used in the equations.

TABLE I. SYMBOLS AND VARIABLES

| Symbol | Definition |
|---|---|
| N | Population size |
| n | Number of iterations |
| D | Number of dimensions |
| Rq | Users' requests |
| Sq | Providers' services |
| Rc | Average cost per user |
| Sc | The average cost for each provider |
| RSc | Average business cost |
| $C_u^p$ | The paid cost by the user u to the provider p |

Eq. (1) and Eq. (2) show the total number of a user's requested and presented items by the provider. Eq. (3) allows for dividing the user's suggested cost by the total number of requested products to determine the average cost per user. The average cost for each provider is the division of the proposed cost by the provider on the total number of provider items shown in Eq. (4). The average business cost of provider p and user u is determined based on the users and the provider's average costs using Eq. (5). The paid cost by the user u to the provider p is estimated through the number of assigned resources using Eq. (6). The earnings of each provider are presented in Eq. (7), which is equal to the paid cost minus the proposed cost in Eq. (6). The higher cost received by the provider for its resources than the expected cost leads to higher earnings by the provider.

Moreover, in each user's income, Eq. (8) equals the proposed cost of the user minus its paid in Eq. (6). It is also clear that more paid cost by the user to rent the requested resources to the provider than its proposed cost makes more earning for the user. The resource utilization rate in Eq. (9) is equal to the ratio of the total number of requested items by a user to the total items presented by the provider. Objective functions in Eq. (10), Eq. (11), and Eq. (12) show the total earnings of the providers, the total income of the users, and total resource utilization, respectively. The objective area in the proposed algorithm is three-dimensional, as shown in Eq. (13).

Moreover, the requested resources should not be more than the provided resources controlled by Eq. (14).

$$Rq_u = \sum_{l=1}^{k} q_k^{u} \qquad (1)$$

$$Sq_p = \sum_{l=1}^{k} q_k^{p} \qquad (2)$$

$$Rc_u = \frac{cost_u}{Rq_u} \qquad (3)$$

$$Sc_p = \frac{cost_p}{Sq_p} \qquad (4)$$

$$RSc_u^{p} = \left( \frac{Rc_u + Sc_p}{2} \right) \qquad (5)$$

$$c_u^{p} = RSc_u^{p} \times Rq_u \qquad (6)$$

$$Submitcost_p = c_u^{p} - cost_p \qquad (7)$$

$$Requestcost_u = cost_u - c_u^{p} \qquad (8)$$

$$quantity_p = \frac{Rq_u}{sq_p} \qquad (9)$$

$$f_1 = \sum_{p=1}^{m} (Submitcost_p) \qquad (10)$$

$$f_2 = \sum_{u=1}^{n} (Requestcost_u) \qquad (11)$$

$$f_3 = \sum_{u=1}^{n} \sum_{p=1}^{m} (quantity) \qquad (12)$$

$$Finess = [f_1\ f_2\ f_3] \qquad (13)$$

$$\sum_{u=1}^{n} \sum_{l=1}^{k} (q_k^{u} \le q_k^{p}\ and\ a_k^{u} \le a_k^{p}) \qquad (14)$$

### B. The Proposed Method for Cloud Resource Assignment

The proposed multi-objective method is proposed based on the PSO algorithm. Here, the algorithm and the way of making it multi-objective are explained. Then, the steps of the proposed method are presented:

*1) Particle swarm optimization algorithm:* The PSO algorithm employs a population-based stochastic process.

Particles move through the search space of an optimization problem. Particles' positions represent potential solutions. The particles search the search space for better positions by modifying their velocities under rules derived from behavior models of flocking birds. The PSO algorithm is known for its adeptness at approaching near-optimal solutions, a characteristic pivotal in addressing resource allocation concerns within cloud computing environments. The time complexity of the PSO algorithm typically operates at O(n*N), where n represents the number of iterations and N stands for the population size or number of particles in the swarm. In terms of space complexity, it generally stands at O(N*D), with D representing the number of dimensions in the given problem space.

*2) Multi-objective particle swarm optimization algorithm:* In MOPSO, a concept called the hall of fame or repository is used so that from the investigated best answers, the best of them that are undefeated answers are stored in a repository. These repository members are an approximation of the Pareto front. Each particle in MOPSO selects one repository's member as a leader when it wants to move. It is the experimented best position of that particle. However, the answers are distributed on a multi-dimensional plate. Vertical and horizontal lines should be used to tabulate the area initially. The cells in the space are then identified, including the repository members. Some cells may have repository members, but the priority is for the cells with less population because of maintaining diversity. One of the less congested cells is selected using the Roulette Wheel Selection method, and then one of the cell's members is selected as leader randomly. Each particle moves using Eq. (15) and Eq. (16).

$$v_{i\ (it+1)} = wv_i^{(it)} + c_1 r_1 (pbest_i^{(it)} - X_i^{(it)}) + c_2 r_2 (gbest^{(it)} - X_i^{(it)}) \qquad (15)$$

$$X_i^{(it+1)} = X_i^{(it)} + v_i^{(it+1)} \qquad (16)$$

The following comparisons should be made between the new role and the top memory: 1) If the new position beats the best memory, the new position replaces the best memory. 2) Nothing is performed if the best memory beats the new position. 3) If none of them is defeated, one of the positions is considered the best memory randomly. Then, undefeated members of the current population are the elites. Now, the quality of the response is controlled. Selecting the repository's member to remove is performed using the Roulette Wheel Selection method, but the cell with fewer roles in the diversity of the answers is selected. Here, the priority is for the cells with more population. The lack of memory has a limit on the repository size. The new members should be removed using the Roulette Wheel Selection method, depending on the crowded cells if the number of repository members exceeds the calculated capacity. A multi-objective problem that requires an agent in every square inch of space is being explored, and the PSO is an algorithm with a high convergence speed. As a

result, a mutation operator slows down convergence to ensure the entire space is thoroughly examined [31].

*3)* The proposed multi-objective particle swarm optimization algorithm through crowding distance

A new particle swarm optimization algorithm called $MOPSO - CD$ is proposed in [32]. A mutation operator is used in this algorithm, like the $MOPSO$ algorithm. Moreover, the crowding distance approach used in this algorithm is proposed in [33] and used in the $NSGA - II$ algorithm. This method is also used in $MOPSO - CD$ to find the optimal answers. The crowding distance for each answer approximates the answers' density around it. The studied problem has three objective functions. At first, the objective function values of each dimension are sorted decreasingly. Then, the previous and next points are selected rather than the problem's objective functions. The fractions of the dimension covered by the ith member of the population in the first, second, and third objective functions are obtained by Eq. (17), (18), and (19), and the crowding distance is obtained by Eq. (20).

$$d_i^1 = \frac{\left| f_1^{i+1} - f_1^{i-1} \right|}{f_1^{max} - f_1^{min}} \tag{17}$$

$$d_i^2 = \frac{\left| f_2^{i+1} - f_2^{i-1} \right|}{f_2^{max} - f_2^{min}} \tag{18}$$

$$d_i^3 = \frac{\left| f_3^{i+1} - f_3^{i-1} \right|}{f_3^{max} - f_3^{min}} \tag{19}$$

$$d_i = d_i^1 + d_i^2 + d_i^3 \tag{20}$$

It is beneficial if the population's ith member covers a bigger area. Hence, the higher priority is for the undefeated answers with higher crowding distance in the PSO algorithm. The undefeated answers in the external repository are sorted through the decreasing crowding distance decreasingly. Then, in each step, one of the top 10% of answers is selected randomly. If the repository is full, one of the last 10% of answers is selected randomly, and the new undefeated answer found in the last iteration replaces it. Algorithm 1 shows different steps of the PSO algorithm. Before the start of the main loop of the algorithm, the users' requests list and the providers' offerings, including the attributes, number, and proposed cost, should be received. Moreover, in the proposed algorithm, the particles' positions are defined as follows:

---

**Algorithm 1.** PSO algorithm

1. Initialize the population:

  1.1. Generate Xi

  1.2. Set particle velocity vi to zero (vi=0)

  1.3. Evaluate the fitness value of particle Xi

  1.4. Set the best position of each particle as Pbesti = Xi

  1.5. Update the global best position gbest with the best particle Xi

---

2. Initialize the number of iterations it = 0

3. Save undefeated answers of Xi in rep

4. Begin iteration:

  4.1. Calculate the crowding distance for each undefeated answer in rep

  4.2. Sort undefeated answers in rep based on their crowding distance in decreasing order

  4.3. For each particle Xi from 1 to nPop:

    4.3.1. Randomly select an optimal guide from the top 10% of the sorted rep for particle Xi and update its position in gbest

    4.3.2. Compute the new speed of each particle using equations (3-15) with c1=1 and c2=1

    4.3.3. Calculate the new position of each particle using equations (3-16)

    4.3.4. Adjust variable values of Xi to fit within the determined limits; if Xi exceeds the limits, reverse its particle speed by multiplying it by -1

    4.3.5. Implement a mutation operation on Xi

    4.3.6. Evaluate the objective function of Xi

  4.4. Update undefeated answers in rep:

    4.4.1. Calculate the crowding distance for each undefeated answer in rep

    4.4.2. Sort the undefeated answers in rep based on crowding distance in decreasing order

    4.4.3. Randomly replace one of the lower 10% of the sorted rep with the new answer Xi

  4.5. Update the best position of each particle if the new position defeats the stored position in memory

  4.6. Increment the iteration count it

5. Repeat steps 3 to 4 until the maximum number of iterations is reached

---

*4) The fuzzy-based approach for the adaptive solution:* Multi-objective optimization algorithms do not result in only one answer; a set of undefeated answers is obtained, the approximations of the first front. If a final answer is required, one of the answers should be selected as the resource allocation objective. To this aim, different methods are presented and used now, like the Fuzzy Set theory *[34]*. A membership function for each objective function is considered in *[35]*, given by Eq. (23).

$$\mu_o^s = \begin{cases} 1 & F_o \leq F_o^{min} \\ \dfrac{F_o^{max} - f_o^s}{F_o^{max} - F_o^{min}} & F_o^{min} < f_o^s < F_o^{max} \\ 0 & F_o \geq F_o^{max} \end{cases} \tag{23}$$

A normalized membership function is obtained using Eq. (24) for each undefeated solution. The best adaptive solution is the answer with the most value for $\mu^s$.

$$\mu^s = \frac{\sum_{o=1}^{Nobj} \mu_o^s}{\sum_{s=1}^{S} \sum_{o=1}^{Nobj} \mu_o^s} \qquad (24)$$

## IV. SIMULATION

The proposed algorithm is simulated on a Microsoft Windows system using Matlab. Experiments are divided into three categories: Small-Scale (SS), Middle-Scale (MS), and Large-Scale (LS). The total number of users and providers related to the three experiments is (20, 5), (15, 50), and (30, 100), respectively. The population size is 75, the maximum number of repetitions is 100, and the personal and collective learning coefficients are 1. The Inertia Weight is W=0.4, and the mutation rate is mu=0.5. The resource attributes are as follows:

- The power and speed of the computer processor are measured by Million Instruction per Second (MIPS) with the range of [220, 1000].

- The memory shows the amount of memory in MB with the range of [256, 512, 1024, 2048].

- The accumulator shows the amount of accumulator in MB with the range of [1500, 40000].

- Bandwidth shows the amount of bandwidth in bits per second with the range of [120, 1000].

- The proposed cost is expressed as the cost unit per million instructions with the range of [0.012-0.1046].

### A. Performance Measures

The performance measures of this work are as follows:

- Total earnings of the provider: proportional to Eq. (10)

- Total incomes of the users: proportional to Eq. (11).

- Total resource utilization: proportional to Eq. (12).

- Generation distance: proportional to the presented model in [26].

- The distance: proportional to the model in [27].

### B. The Experimental Results

Two distinct experiments are conducted in this study. Each experiment compares the performance of the suggested method with that of the other methods.

*1) First experiment:* In this experiment, the proposed method performance is compared with NSGA-II *[36]* and MOPSO *[37]* algorithms in terms of the answers' quality, generation distance, distance, and execution time. Tables II to IV show the comparison of these three algorithms comparisons through the previously explained six measures for three types of experiments. Based on three types of experiments, the results for the provider's total earnings, the total users' income, the total resource utilization, and the generation distance for each algorithm are shown in Fig. 2 to Fig. 5. The performance of the proposed algorithm is superior to those of the other three algorithms. Fig. 6 to Fig. 7 illustrate the distance and execution time results for the mentioned algorithms. The proposed algorithm had an average improvement rate of 51% in total resource utilization, 50% in generation distance, and 16.5% in execution time when compared with MOPSO.

*2) Second experiment:* Here, the proposed method's performance is compared with the Artificial Fish Swarm Optimization algorithm (AFSO) [38]. This experiment examines the proposed method's time, cost, and energy efficiency. Fig. 8 illustrates the performance of the proposed method. As the number of tasks increases, the execution time will also increase. Fig. 9 illustrates an analysis of the performance in terms of cost. System performance is affected by the maximum cost. Fig. 10 also illustrates performance in terms of energy consumption. An increase in energy means an increase in cost as well. The proposed algorithm improved the total execution time by 22%, cost by 9%, and energy consumption by 21% compared with AFSO.

TABLE II. STATISTICAL COMPARISON FOR SMALL-SCALE

| Parameters | NSGA-II | MOPSO | PSO-fuzzy |
|---|---|---|---|
| Total earnings of the provider | 0.0852 | 0.01123 | 0.1952 |
| Total incomes of the users | 0.2962 | 0.3740 | 0.5124 |
| Total resource utilization | 5.5175 | 7.0364 | 12.212 |
| Generation distance | 0.0385 | 0.022 | 0.00931 |
| The distance | 0.0545 | 0.0928 | 0.03012 |
| Execution time (sec) | 64.51 | 18.74 | 11.12 |

TABLE III.    STATISTICAL COMPARISON FOR MIDDLE-SCALE

| Parameters | NSGA-II | MOPSO | PSO-fuzzy |
|---|---|---|---|
| Total earnings of the provider | 0.1786 | 0.2340 | 0.561 |
| Total incomes of the users | 0.5908 | 0.7710 | 2.1325 |
| Total resource utilization | 15.7246 | 19.2885 | 42.124 |
| Generation distance | 0.0067 | 0.0043 | 0.0012 |
| The distance | 0.0197 | 0.0394 | 0.00124 |
| Execution time (sec) | 68.187565 | 22.224956 | 15.324 |

TABLE IV.    STATISTICAL COMPARISON FOR LARGE-SCALE

| Parameters | NSGA-II | MOPSO | PSO-fuzzy |
|---|---|---|---|
| Total earnings of the provider | 1.0241 | 1.3480 | 2.125 |
| Total incomes of the users | 1.3848 | 2.0113 | 3.163 |
| Total resource utilization | 31.2672 | 42.2504 | 65.260 |
| Generation distance | 0.0124 | 0.0062 | 0.00325 |
| The distance | 0.0421 | 0.0784 | 0.0231 |
| Execution time (sec) | 87.255300 | 28.799435 | 18.215 |
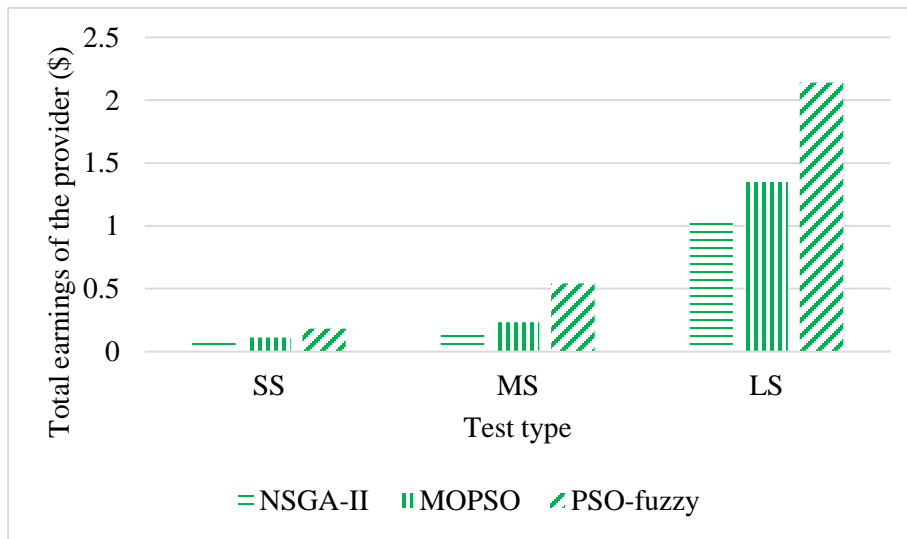
Fig. 2.   Total earnings of the provider comparison.
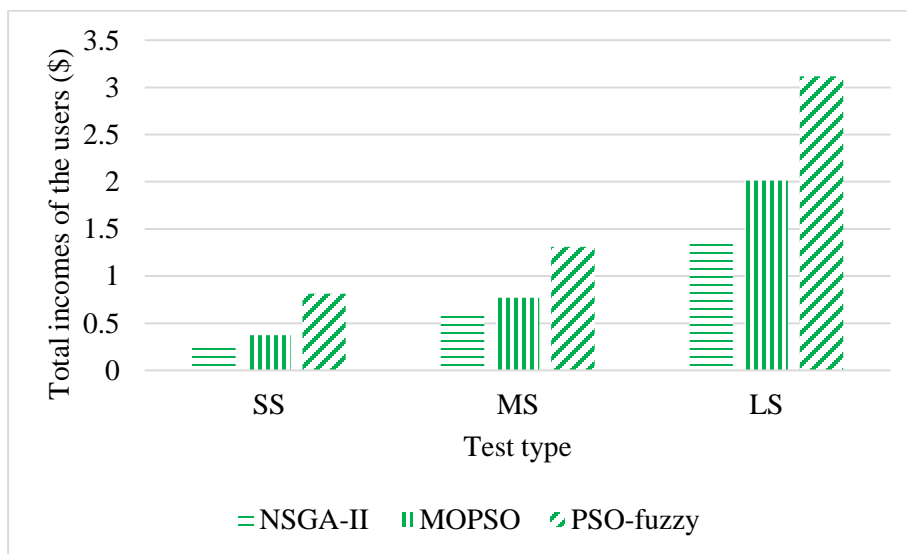
Fig. 3.   Total incomes of the user's comparison.
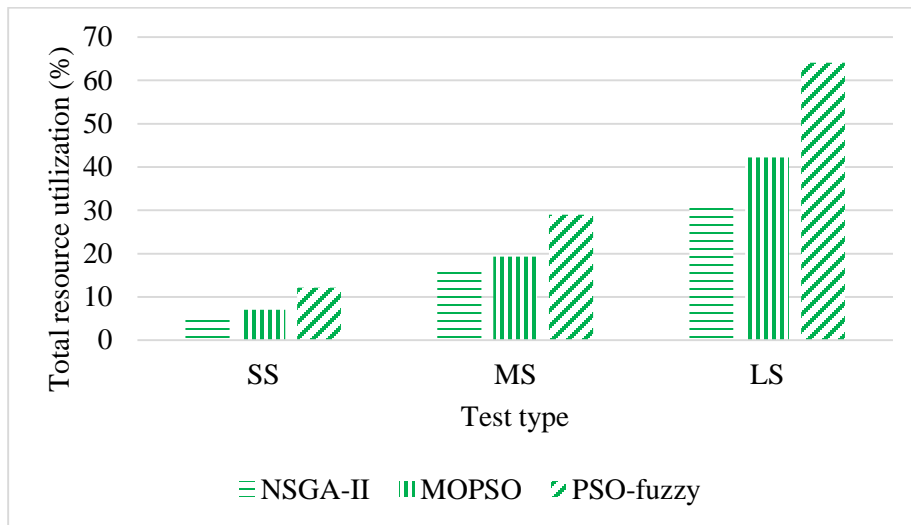
Fig. 4.   Total resource utilization comparison.
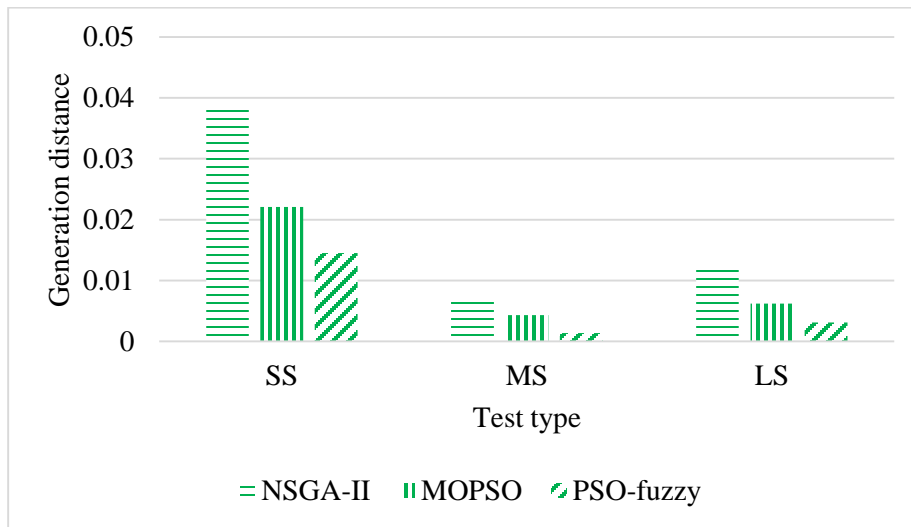


Fig. 5.   Generation distance comparison.
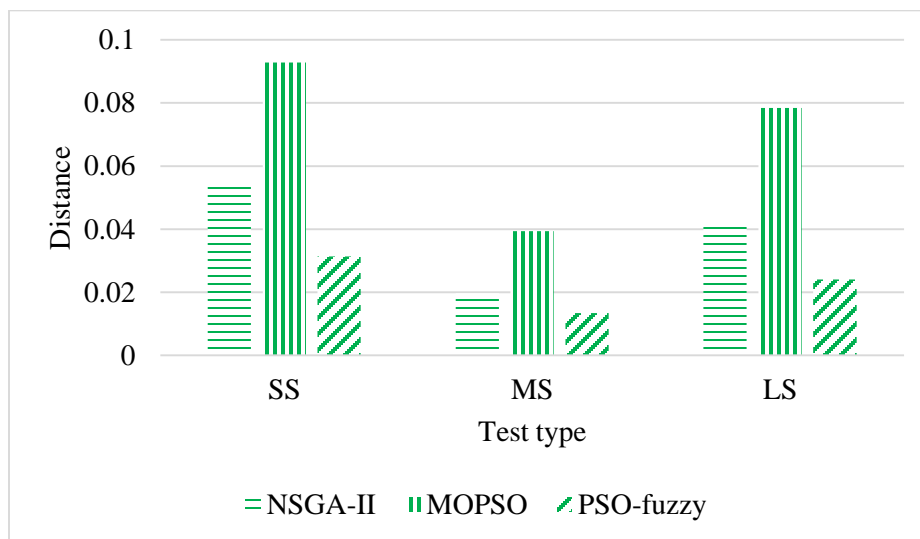


Fig. 6.   The distance comparison.
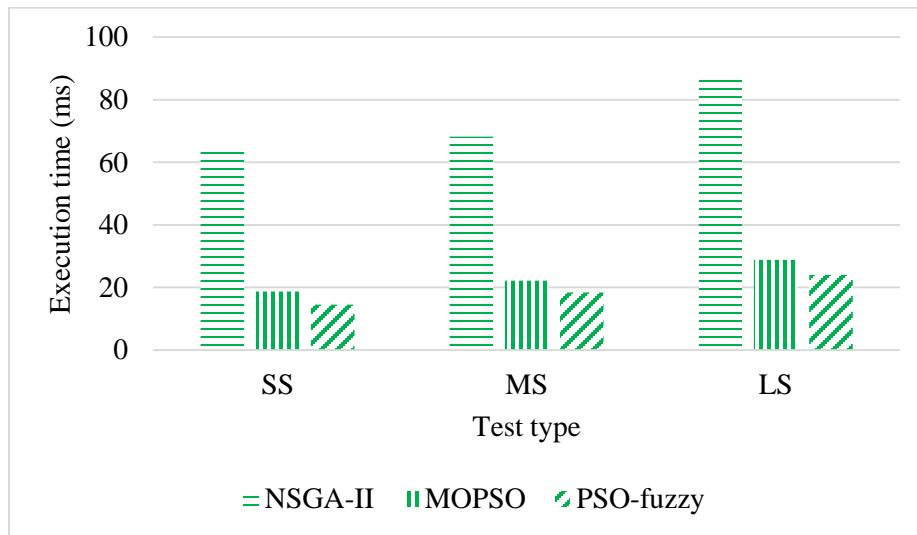
Fig. 7.   Execution time comparison.
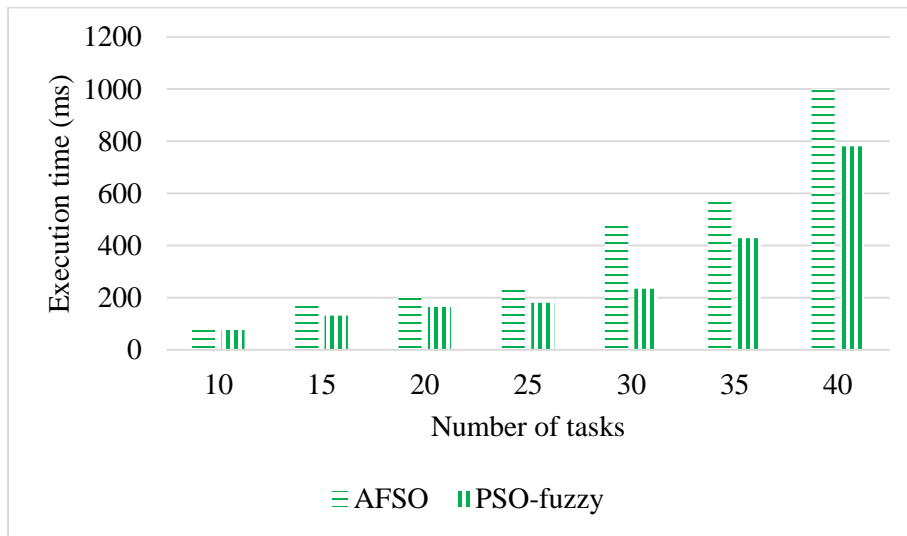


Fig. 8.   Execution time comparison.
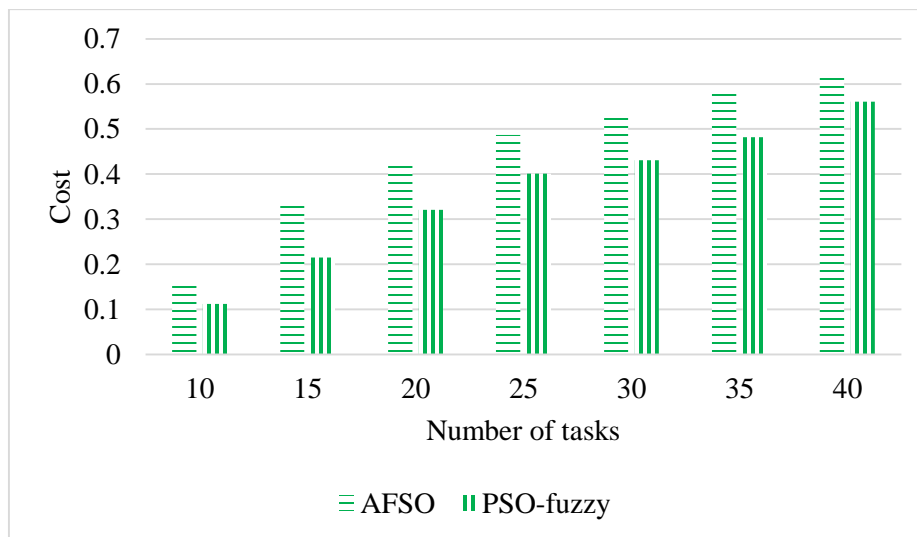


Fig. 9.   Cost comparison.
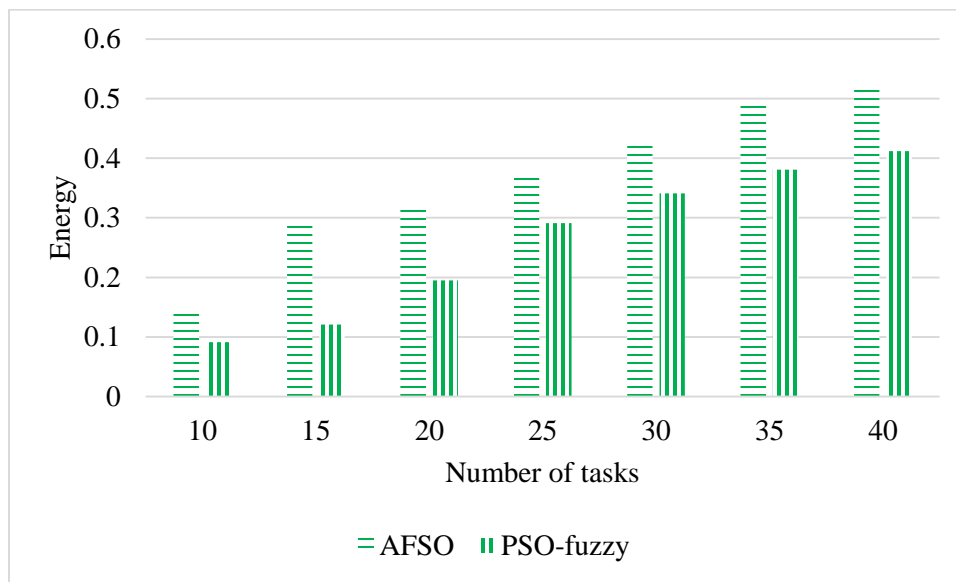
Fig. 10. Energy consumption comparison.

Performance measures expressed proportionally through specific mathematical models encompass key indicators such as total provider earnings, user incomes, resource utilization, generation distance, and execution time. In the first experiment, the PSO-fuzzy algorithm's performance is benchmarked against NSGA-II and MOPSO algorithms, showcasing superior results across various metrics. Notably, the proposed algorithm exhibits an average improvement of 51% in resource utilization, a 50% enhancement in generation distance, and a substantial 16.5% reduction in execution time compared to MOPSO. The PSO-fuzzy methodology is pitted against the Artificial Fish Swarm Optimization (AFSO) algorithm in the second experiment. The results highlight a marked improvement in execution time by 22%, cost efficiency by 9%, and a notable 21% reduction in energy consumption when compared to AFSO. These findings underscore the robustness and efficiency of the PSO-fuzzy algorithm in optimizing resource allocation and cost management across varying scales and scenarios within cloud computing environments.

## V. CONCLUSIONS

This paper proposed an optimal resource allocation method combining the PSO algorithm and fuzzy logic system based on the presented time and cost models in the cloud computing environment. The time model includes receiving, processing, and waiting times. Costs associated with processing and receiving are included in the cost model. The PSO algorithm was applied to the cloud environment for optimal resource allocation. The fuzzy logic system was used to evaluate the time and cost models. The proposed algorithm's efficacy was clearly demonstrated through a series of meticulously designed experiments. In the initial experiment, comparative analysis against established algorithms, namely NSGA-II and MOPSO, revealed the superiority of our method concerning providers' total income, users' total revenue, and resource utilization. Subsequently, the second experiment showcased the algorithm's superior performance in execution time, cost-

effectiveness, and energy consumption when juxtaposed with the AFSO algorithm. These results unequivocally establish the proposed algorithm's prowess, emphasizing its effectiveness in both performance and efficiency metrics. The outcomes affirm the superiority of our algorithm for scheduling within cloud computing systems, surpassing existing methodologies. The success of this approach not only underscores its potential in addressing the resource allocation challenge but also signifies a significant stride toward optimizing cloud computing operations. However, while these results are promising, future work should delve into further validation across a more extensive range of scenarios and consider real-world implementations to solidify the algorithm's robustness and applicability in diverse cloud environments.

## REFERENCES

[1] B. Pourghebleh, A. A. Anvigh, A. R. Ramtin, and B. Mohammadi, "The importance of nature-inspired meta-heuristic algorithms for solving virtual machine consolidation problem in cloud environments," Cluster Computing, pp. 1-24, 2021.

[2] M. Mohseni, F. Amirghafouri, and B. Pourghebleh, "CEDAR: A cluster-based energy-aware data aggregation routing protocol in the internet of things using capuchin search algorithm and fuzzy logic," Peer-to-Peer Networking and Applications, pp. 1-21, 2022.

[3] B. Pourghebleh, N. Hekmati, Z. Davoudnia, and M. Sadeghi, "A roadmap towards energy-efficient data fusion methods in the Internet of Things," Concurrency and Computation: Practice and Experience, p. e6959, 2022.

[4] S. Bharany et al., "Energy efficient fault tolerance techniques in green cloud computing: A systematic survey and taxonomy," Sustainable Energy Technologies and Assessments, vol. 53, p. 102613, 2022.

[5] H. Feng, Y. Deng, and J. Li, "A global-energy-aware virtual machine placement strategy for cloud data centers," Journal of Systems Architecture, vol. 116, p. 102048, 2021.

[6] G. J. Ibrahim, T. A. Rashid, and M. O. Akinsolu, "An energy efficient service composition mechanism using a hybrid meta-heuristic algorithm in a mobile cloud environment," Journal of parallel and distributed computing, vol. 143, pp. 77-87, 2020.

[7] K. Karthikeyan et al., "Energy consumption analysis of Virtual Machine migration in cloud using hybrid swarm optimization (ABC–BA)," The Journal of Supercomputing, vol. 76, no. 5, pp. 3374-3390, 2020.

[8] M. Yavari, A. G. Rahbar, and M. H. Fathi, "Temperature and energy-aware consolidation algorithms in cloud computing," Journal of Cloud Computing, vol. 8, no. 1, pp. 1-16, 2019.

[9] W. Shu, K. Cai, and N. N. Xiong, "Research on strong agile response task scheduling optimization enhancement with optimal resource usage in green cloud computing," Future Generation Computer Systems, vol. 124, pp. 12-20, 2021.

[10] V. Hayyolalam, B. Pourghebleh, M. R. Chehrehzad, and A. A. Pourhaji Kazem, "Single-objective service composition methods in cloud manufacturing systems: Recent techniques, classification, and future trends," Concurrency and Computation: Practice and Experience, vol. 34, no. 5, p. e6698, 2022.

[11] P. Behrouz, H. Vahideh, and A. A. Aghaei, "Service discovery in the Internet of Things: review of current trends and research challenges," Wireless Networks, vol. 26, no. 7, pp. 5371-5391, 2020.

[12] T. Baker, M. Asim, H. Tawfik, B. Aldawsari, and R. Buyya, "An energy-aware service composition algorithm for multiple cloud-based IoT applications," Journal of Network and Computer Applications, vol. 89, pp. 96-108, 2017.

[13] H. Vahideh, P. Behrouz, P. K. A. Asghar, and A. Ghaffari, "Exploring the state-of-the-art service composition approaches in cloud manufacturing systems to enhance upcoming techniques," The International Journal of Advanced Manufacturing Technology, vol. 105, no. 1-4, pp. 471-498, 2019.

[14] R. Singh et al., "Analysis of Network Slicing for Management of 5G Networks Using Machine Learning Techniques," Wireless Communications and Mobile Computing, vol. 2022, 2022.

[15] B. Pourghebleh and V. Hayyolalam, "A comprehensive and systematic review of the load balancing mechanisms in the Internet of Things," Cluster Computing, pp. 1-21, 2019.

[16] P. He, N. Almasifar, A. Mehbodniya, D. Javaheri, and J. L. Webber, "Towards green smart cities using Internet of Things and optimization algorithms: A systematic and bibliometric review," Sustainable Computing: Informatics and Systems, vol. 36, p. 100822, 2022, doi: https://doi.org/10.1016/j.suscom.2022.100822.

[17] S. N. H. Bukhari, J. Webber, and A. Mehbodniya, "Decision tree based ensemble machine learning model for the prediction of Zika virus T-cell epitopes as potential vaccine candidates," Scientific Reports, vol. 12, no. 1, p. 7810, 2022.

[18] F. Kamalov, B. Pourghebleh, M. Gheisari, Y. Liu, and S. Moussa, "Internet of Medical Things Privacy and Security: Challenges, Solutions, and Future Trends from a New Perspective," Sustainability, vol. 15, no. 4, p. 3317, 2023.

[19] B. M. Jafari, M. Zhao, and A. Jafari, "Rumi: An Intelligent Agent Enhancing Learning Management Systems Using Machine Learning Techniques," Journal of Software Engineering and Applications, vol. 15, no. 9, pp. 325-343, 2022.

[20] J. Webber, A. Mehbodniya, Y. Hou, K. Yano, and T. Kumagai, "Study on idle slot availability prediction for WLAN using a probabilistic neural network," in 2017 23rd Asia-Pacific Conference on Communications (APCC), 2017: IEEE, pp. 1-6.

[21] S. Aghakhani, A. Larijani, F. Sadeghi, D. Martín, and A. A. Shahrakht, "A Novel Hybrid Artificial Bee Colony-Based Deep Convolutional Neural Network to Improve the Detection Performance of Backscatter Communication Systems," Electronics, vol. 12, no. 10, p. 2263, 2023.

[22] M. Sadi et al., "Special Session: On the Reliability of Conventional and Quantum Neural Network Hardware," in 2022 IEEE 40th VLSI Test Symposium (VTS), 2022: IEEE, pp. 1-12.

[23] Z. Wang and X. Su, "Dynamically hierarchical resource-allocation algorithm in cloud computing environment," The Journal of Supercomputing, vol. 71, no. 7, pp. 2748-2766, 2015.

[24] H. Jiang, J. Yi, S. Chen, and X. Zhu, "A multi-objective algorithm for task scheduling and resource allocation in cloud-based disassembly," Journal of Manufacturing Systems, vol. 41, pp. 239-255, 2016.

[25] S. Mousavi, A. Mosavi, and A. R. Varkonyi-Koczy, "A load balancing algorithm for resource allocation in cloud computing," in International conference on global research and education, 2017: Springer, pp. 289-296.

[26] M. Ficco, C. Esposito, F. Palmieri, and A. Castiglione, "A coral-reefs and game theory-based approach for optimizing elastic cloud resource allocation," Future Generation Computer Systems, vol. 78, pp. 343-352, 2018.

[27] X. Chen, H. Wang, Y. Ma, X. Zheng, and L. Guo, "Self-adaptive resource allocation for cloud-based software services based on iterative QoS prediction model," Future Generation Computer Systems, vol. 105, pp. 287-296, 2020.

[28] R. Singhal and A. Singhal, "A feedback-based combinatorial fair economical double auction resource allocation model for cloud computing," Future Generation Computer Systems, vol. 115, pp. 780-797, 2021.

[29] A. Thakur and M. S. Goraya, "RAFL: A hybrid metaheuristic based resource allocation framework for load balancing in cloud computing environment," Simulation Modelling Practice and Theory, vol. 116, p. 102485, 2022.

[30] L. Li, Y.-a. LIU, K.-m. LIU, and Y. Ming, "Pricing in combinatorial double auction-based grid allocation model," The Journal of China Universities of Posts and Telecommunications, vol. 16, no. 3, pp. 59-65, 2009.

[31] P. Samimi, Y. Teimouri, and M. Mukhtar, "A combinatorial double auction resource allocation model in cloud computing," Information Sciences, 2014.

[32] C. R. Raquel and P. C. Naval Jr, "An effective use of crowding distance in multiobjective particle swarm optimization," in Proceedings of the 7th Annual conference on Genetic and Evolutionary Computation, 2005: ACM, pp. 257-264.

[33] K. Deb, A. Pratap, S. Agarwal, and T. Meyarivan, "A fast and elitist multiobjective genetic algorithm: NSGA-II," Evolutionary Computation, IEEE Transactions on, vol. 6, no. 2, pp. 182-197, 2002.

[34] K. Miettinen, "Nonlinear Multiobjective Optimization, volume 12 of International Series in Operations Research and Management Science," ed: Kluwer Academic Publishers, Dordrecht, 1999.

[35] L. Wang and C. Singh, "Environmental/economic power dispatch using a fuzzified multi-objective particle swarm optimization algorithm," Electric Power Systems Research, vol. 77, no. 12, pp. 1654-1664, 2007.

[36] L. Xu, Z. Zeng, and X. Ye, "Multi-objective optimization based virtual resource allocation strategy for cloud computing," in Computer and Information Science (ICIS), 2012 IEEE/ACIS 11th International Conference on, 2012: IEEE, pp. 56-61.

[37] M. Feng, X. Wang, Y. Zhang, and J. Li, "Multi-objective particle swarm optimization for resource allocation in cloud computing," in Cloud Computing and Intelligent Systems (CCIS), 2012 IEEE 2nd International Conference on, 2012, vol. 3: IEEE, pp. 1161-1165.

[38] P. Albert and M. Nanjappan, "An efficient kernel FCM and artificial fish swarm optimization-based optimal resource allocation in cloud," Journal of Circuits, Systems and Computers, vol. 29, no. 16, p. 2050253, 2020.

# Efficient Cloud Workflow Scheduling with Inverted Ant Colony Optimization Algorithm

Hongwei DING, Ying ZHANG*

Hebei Software Institute, Hebei, Bao ding, 071000, China

*Abstract*—Cloud computing has risen as a prominent paradigm, offering users on-demand access to computing resources and services via the Internet. In cloud environments, workflow scheduling plays a vital role in optimizing resource utilization, reducing execution time, and minimizing overall costs. As workflows comprise interdependent tasks that need to be assigned to Virtual Machines (VMs), the complexity of the scheduling problem increases in proportion to workflow size and VM availability. Due to its NP-hard nature, finding an optimal scheduling solution for workflows remains a challenging task. To address this problem, researchers have turned to metaheuristic approaches, which have shown promise in finding near-optimal solutions for complex combinatorial optimization problems. This paper proposes a novel metaheuristic algorithm called Inverted Ant Colony Optimization (IACO) for workflow scheduling in cloud environments. IACO is a variation of the traditional ACO algorithm, where the updated pheromone has an inverted influence on the path chosen by the ants. By leveraging the complementary nature of these two algorithms, our proposed algorithm aims to achieve superior workflow scheduling performance regarding total execution time and cost, surpassing existing approaches.

*Keywords—Cloud computing; workflow scheduling; virtualization; task allocation; swarm intelligence; optimization*

## I. INTRODUCTION

Cloud computing is a technological advancement that harnesses the capabilities of the Internet and distant centralized servers to supply users with flexible services. These services are delivered using a diverse range of distributed resources, catering to various quality of service (QoS) requirements [1]. Prominent cloud computing platforms include Aneka, Microsoft Azure, Google App Engine, and Amazon EC2. Clouds are generally classified into several types: public, private, community, hybrid, and cloud federation [2]. Public clouds are accessible to the general public and are owned and managed by external entities known as independent cloud service providers. Computing resources, like applications, storage, and servers, are available to an array of businesses or individuals [3].

In contrast, private clouds are owned by an individual organization and are either hosted internally or handled exclusively by an external provider for that organization's use [4]. Community clouds are shared among multiple organizations with similar interests or requirements. These clouds are designed to cater to the specific needs of a particular community, such as government agencies, educational institutions, or healthcare providers [5]. Hybrid clouds integrate elements from both public and private clouds. In this

model, organizations can distribute applications and data across multiple cloud deployment models, interconnected to function as a cohesive infrastructure. Cloud federation involves the interconnection and collaboration of multiple cloud infrastructures to work as a single unified cloud environment. It enables seamless movement of workloads and data among different cloud providers, enhancing flexibility and scalability in cloud computing [6].

Cloud computing is categorized into three primary service models: Software-as-a-Service (SaaS), Platform-as-a-Service (PaaS), and Infrastructure-as-a-Service (IaaS) [7]. In SaaS, software applications are delivered to users online through subscriptions. Users can use these services remotely without installation or local device maintenance. The responsibility for hosting, maintenance, and updates lies with the SaaS provider. PaaS offers a platform for developers to build, deploy, and manage applications with no need for infrastructure management. PaaS provides developers with access to a set of development tools, programming languages, and runtime environments, facilitating the creation and execution of applications. In IaaS, users subscribe to virtual machines, servers, networking components, and other infrastructure resources from a cloud provider. IaaS gives customers enhanced control over infrastructure without requiring them to invest in physical hardware and its maintenance [8].

Virtualization is a critical technology in cloud computing that enables the coexistence of multiple Virtual Machines (VMs) on a single physical machine. A VM is a simulated computer system that executes tasks assigned by users. This capacity for VM instantiation empowers users to run their applications across resources that encompass diverse functionality and cost attributes. Orchestrating this arrangement within each physical machine or server is a software layer, colloquially referred to as the hypervisor or VM monitor. The hypervisor serves as a facilitator for VM creation and ensures their isolated execution, allowing multiple VMs to operate independently and securely on the same physical hardware. The hypervisor is responsible for efficiently managing the allocation of resources and providing a seamless and robust virtualization environment for cloud computing [9].

Workflow scheduling poses a substantial challenge within the context of cloud computing, entailing the intricate assignment of workflow tasks to VMs based on a multitude of operational and technical requisites [10]. Workflows are constructed from an array of interdependent tasks, interlinked by either data or functional dependencies, necessitating meticulous consideration during the scheduling endeavor. Nonetheless, the task of workflow scheduling in cloud

environments is classified as an NP-hard optimization problem, rendering the attainment of an optimal schedule a formidable undertaking [11]. The cloud environment typically encompasses a multitude of VMs, engendering intricacies in orchestrating an array of user tasks while accounting for diverse scheduling objectives and elements. For instance, a scheduling scheme may prioritize supporting Service Level Agreements (SLAs), predetermined timeframes, and cost limitations. Additionally, scheduling strategies may take into account parameters like the availability of cloud resources and services, load balancing, and resource utilization to make informed scheduling plans.

The integration of cutting-edge technologies such as the Internet of Things (IoT), machine learning, deep learning, and neural networks has revolutionized workflow scheduling, particularly in cloud environments. The IoT facilitates the interconnectedness of devices and sensors, offering real-time data collection and sharing [12, 13]. Machine learning techniques, including supervised and unsupervised algorithms, analyze this data to predict and optimize workflow patterns [14, 15]. Deep learning, a subset of machine learning, uses intricate neural network architectures to process complex data representations, making it adept at recognizing patterns and optimizing scheduling decisions [16]. Neural networks, inspired by the human brain's structure, excel in learning from data and making informed decisions based on this acquired knowledge [17]. Their application in workflow scheduling involves predictive analysis, resource allocation, and task optimization [18]. Collectively, these technologies enable intelligent decision-making, predictive scheduling, and adaptive allocation of tasks within cloud environments. By harnessing IoT data with machine learning, deep learning, and neural networks, workflow scheduling becomes more agile, responsive, and adept at handling the dynamic and complex demands of cloud-based applications, ultimately improving efficiency, resource utilization, and overall performance. Their integration not only streamlines operations but also paves the way for self-optimizing and self-adapting systems in cloud workflow management [19, 20].

Meta-heuristic algorithms are key to workflow scheduling within cloud computing due to the inherent complexity of task allocation. These algorithms, by their nature of adaptive and efficient search strategies, offer an effective way to navigate the vast solution space, addressing the NP-hard nature of scheduling problems [21]. They enable the optimization of resource allocation, contributing significantly to reduced execution times, minimized costs, and improved overall efficiency in cloud-based workflow management. Inverted Ant Colony Optimization (IACO) represents a deviation from the conventional ACO algorithm, which is a metaheuristic derived from the foraging behavior of real ants. In ACO, ants construct solutions by probabilistically choosing paths in a graph based on pheromone trails and heuristic information. The pheromone trails reflect the attractiveness of edges in the graph, and ants deposit pheromones on the paths they traverse. Over time, paths with higher pheromone concentrations become more attractive to other ants, leading to the emergence of high-quality solutions. The IACO algorithm introduces a novel concept to the ACO framework called "inversion." In the traditional ACO, the pheromone trail is reinforced for successful paths, and it is evaporated gradually to encourage exploration. However, in IACO, the pheromone trail on the best path (i.e., the path with the highest desirability) is reduced instead of increased during the pheromone update process. This reduction is referred to as "inversion". The core idea behind the inversion mechanism in IACO is to enhance exploration capabilities. By reducing the pheromone level on the best path, the algorithm encourages ants to explore alternative routes rather than always favoring the currently best-known path. This helps in diversifying the search space and prevents the algorithm from getting stuck in local optima. For workflow scheduling in cloud computing, IACO is applied to find an optimized allocation of tasks to VMs, aiming to lower the total execution time and overall costs. In this context, the graph represents the task dependency graph, and ants traverse paths by assigning tasks to available virtual machines. The main contributions of the study can be summarized as follows:

- Adaptation of traditional ACO algorithm with an inversion mechanism to enhance exploration capabilities and prevent local optima convergence.

- Improvement in the allocation of tasks to VMs, leading to reduced total execution time and minimized costs in cloud-based workflow scheduling.

- Establishment of a pioneering approach that sets a potential benchmark for optimization in cloud computing, influencing future research and practical implementations.

## II. RELATED WORK

Choudhary, et al. [22] combined the Heterogeneous Earliest Finish Time (HEFT) heuristic and the Gravitational Search Algorithm (GSA) for workflow scheduling. The GSA is a powerful meta-heuristic that imitates the law of gravity to search for optimal solutions, while HEFT is a widely used heuristic that schedules tasks based on their earliest finish times on heterogeneous resources. One of the key contributions of their work is the introduction of a new factor called "cost time equivalence," which enhances the realism of the bi-objective optimization process. By considering the monetary cost ratio (MCR) and the schedule length ratio (SLR) as performance metrics, they compare the proposed algorithm's performance with existing algorithms. To validate their results, rigorous experiments are conducted over various scientific workflows. They demonstrate the effectiveness of their proposed algorithm by comparing it with standard GSA, Hybrid Genetic Algorithm (HGA), and HEFT. Statistical tests, such as Analysis of Variance (ANOVA), are utilized to validate the results. The simulation results consistently show that the proposed approach outperforms the existing algorithms in terms of both makespan and cost optimization. The algorithm's effectiveness is demonstrated across different workflow scenarios, providing robust evidence of its superiority over the compared algorithms.

Elsherbiny, et al. [23] introduced a novel algorithm that extends the Intelligent Water Drops (IWD) algorithm, a nature-inspired optimization method, to optimize the scheduling of workflows in cloud computing environments. The suggested

algorithm is applied and incorporated into the workflow simulation toolkit, allowing for comprehensive testing in various simulated cloud environments with different cost models. The results of the experiments demonstrate that the proposed IWD-based algorithm outperforms classical workflow scheduling algorithms in terms of both performance and cost. They conducted a thorough comparison with several well-known scheduling algorithms. In most situations, the proposed IWD-based algorithm exhibited noticeable enhancements in terms of both performance and cost, outperforming the alternative algorithms. This showcases the effectiveness and efficiency of the IWD-based approach in optimizing workflow scheduling for cloud computing environments.

Ismayilov and Topcuoglu [24] address the intricate challenge of dynamic workflow scheduling within the context of a Dynamic Multi-Objective Optimization Problem (DMOP). This dynamic aspect arises from two primary sources: resource failures (manifested as software or hardware faults) and the inherent variability in the number of objectives during the execution of workflows in real-world cloud computing scenarios. To surmount this intricate problem, the authors propose an innovative prediction-based dynamic multi-objective evolutionary algorithm named NN-DNSGA-II. This algorithm ingeniously combines the capabilities of an artificial neural network with the NSGA-II algorithm, allowing it to make informed predictions concerning the evolving objectives and subsequently adapt its strategies accordingly. The study also involves the adaptation of five prominent non-prediction-based dynamic algorithms from the existing literature, with the overarching goal of addressing the dynamic workflow scheduling dilemma. The NN-DNSGA-II algorithm is thoughtfully designed to encompass six distinct objectives within the scheduling process. It aims to minimize critical aspects such as makespan, cost, energy consumption, and degree of imbalance while simultaneously maximizing attributes like reliability and utilization. To assess its efficacy, the authors conducted comprehensive empirical studies employing real-world applications sourced from the Pegasus workflow management system. This rigorous evaluation entails a range of metrics tailored for DMOPs characterized by unknown true Pareto-optimal fronts. Metrics include considerations such as the number of non-dominated solutions, Schott's spacing, and the Hypervolume indicator. The findings derived from the empirical investigation reveal the remarkable performance of the NN-DNSGA-II algorithm. It consistently outperforms alternative algorithms across various scenarios, underlining its supremacy in effectively managing dynamic workflow scheduling imbued with multiple objectives and unknown true Pareto-optimal fronts.

Mangalampalli, et al. [25] introduced a novel workflow-scheduling mechanism that incorporates task priorities to schedule tasks onto appropriate virtual resources efficiently. The Whale Optimization Algorithm (WOA) was used as the methodology to model this algorithm. Extensive simulations were conducted using the workflow simulator to evaluate the proposed mechanism's performance. The mechanism was compared against existing algorithms, including PSO, CS, ACO, and GA. The simulation results revealed significant improvements in makespan, migration time, and energy consumption when using the proposed mechanism. These improvements indicate the effectiveness of the WOA-based workflow-scheduling approach in optimizing task scheduling in cloud computing environments. By considering task priorities, the proposed mechanism is able to make more informed and efficient scheduling decisions, leading to reduced makespan (total execution time), migration time (task relocation between resources), and energy consumption. These improvements are crucial for enhancing the overall performance and resource utilization in cloud-based workflow management.

Zeedan, et al. [26] introduced an innovative approach termed Enhanced Binary Artificial Bee Colony-based Pareto Front (EBABC-PF) for optimizing workflow scheduling in cloud computing environments. The proposed approach involves a sequence of strategic steps aimed at achieving efficient task scheduling. The initial step of the approach involves task prioritization using the HEFT algorithm. HEFT organizes tasks based on their earliest finish times across heterogeneous resources, thereby establishing a prioritized sequence. Subsequently, an initial solution is constructed using the Greedy Randomized Adaptive Search Procedure (GRASP), a constructive metaheuristic approach renowned for its optimization capabilities. The core task scheduling phase is executed through the utilization of the enhanced Binary Artificial Bee Colony (BABC) algorithm. This modified version of the BABC algorithm integrates several enhancements specifically targeted at refining the local search process. The process incorporates circular shift and mutation operators, which are applied to the population's food sources while considering the improvement rate. These enhancements contribute to augmenting the algorithm's search capacity and effectiveness. The proposed EBABC-PF approach is simulated and implemented using WorkflowSim, an extension of the CloudSim tool designed to manage workflows within cloud environments. To assess its performance, the approach is rigorously compared against a range of other scheduling algorithms, which include HEFT, Deadline Heterogeneous Earliest Finish Time (DHEFT), Non-dominated Sort Genetic Algorithm (NSGA-II), and the standard BABC algorithm. This comparative analysis is conducted across diverse task sizes and benchmark workflows. The simulation results obtained exhibit the exceptional efficiency of the proposed EBABC-PF approach across multiple performance metrics. It notably outperforms the alternative algorithms in terms of makespan (total execution time), processing cost, and resource utilization. This finding underscores the approach's effectiveness in optimizing workflow scheduling within cloud computing environments, rendering it a superior choice for this intricate task.

## III. Proposed Approach

### A. Problem Statement

In the domain of cloud computing, workflow scheduling involves the representation of workflows as Directed Acyclic Graphs (DAGs), denoted as $G = (V, E)$. $V$ refers to a collection of vertices, each representing an individual task within the workflow. $E$, on the other hand, denotes the set of edges

signifying task dependencies. In this setup, tasks must be executed in a specific order, where parent tasks precede the execution of their child tasks. Fig. 1 offers a concrete illustration of task dependencies spanning from $T_1$ to $T_{10}$. Serving as the root node, $T_1$ takes the lead as the first task to be executed. Once $T_1$ is finished, tasks $T_2$ and $T_3$, located on the first tier of the DAG, are initiated. In a parallel manner, once task $T_2$ is accomplished, tasks $T_4$ and $T_5$ are set into motion.

Additionally, the execution of task $T_6$ is contingent upon the completion of task $T_3$, thus establishing $T_3$ as the necessary precursor to $T_6$. Scientific workflows encompass a specialized class of workflows extensively utilized across a range of scientific fields, such as astronomy, biology, and gravitational waves, among others. Prominent instances of practical scientific workflows include SIPHT, LIGO, Epigenomics, CyberShake, and Montage, all meticulously cataloged by the Pegasus project. The structural depiction of these scientific workflows is presented in Fig. 2. The scheduling of workflows can be perceived as a mapping function, allocating numerous interdependent tasks to available virtual machines. A sample mapping is illustrated in Fig. 3, demonstrating the allocation of n tasks to m VMs. In such instances, when employing a brute

force algorithm, there emerge $m*n$ potential combinations. Consequently, the intricacy of workflow scheduling is acknowledged, and achieving a solution within polynomial time is not attainable. Consequently, the pursuit of a nearly optimal resolution to the workflow scheduling predicament proves advantageous and attainable through the assistance of meta-heuristic algorithms.
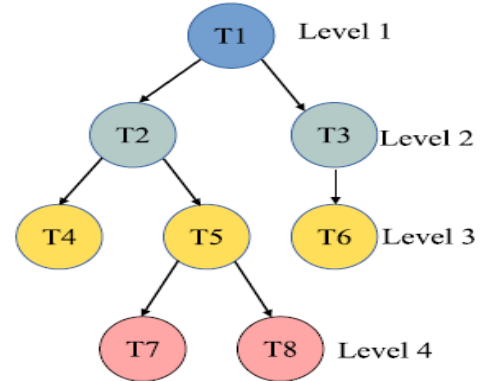


Fig. 1. Task dependencies in workflow scheduling



(a) Montage     (b) CyberShake     (c) Epigenomics

(d) SIPHT     (e) LIGO
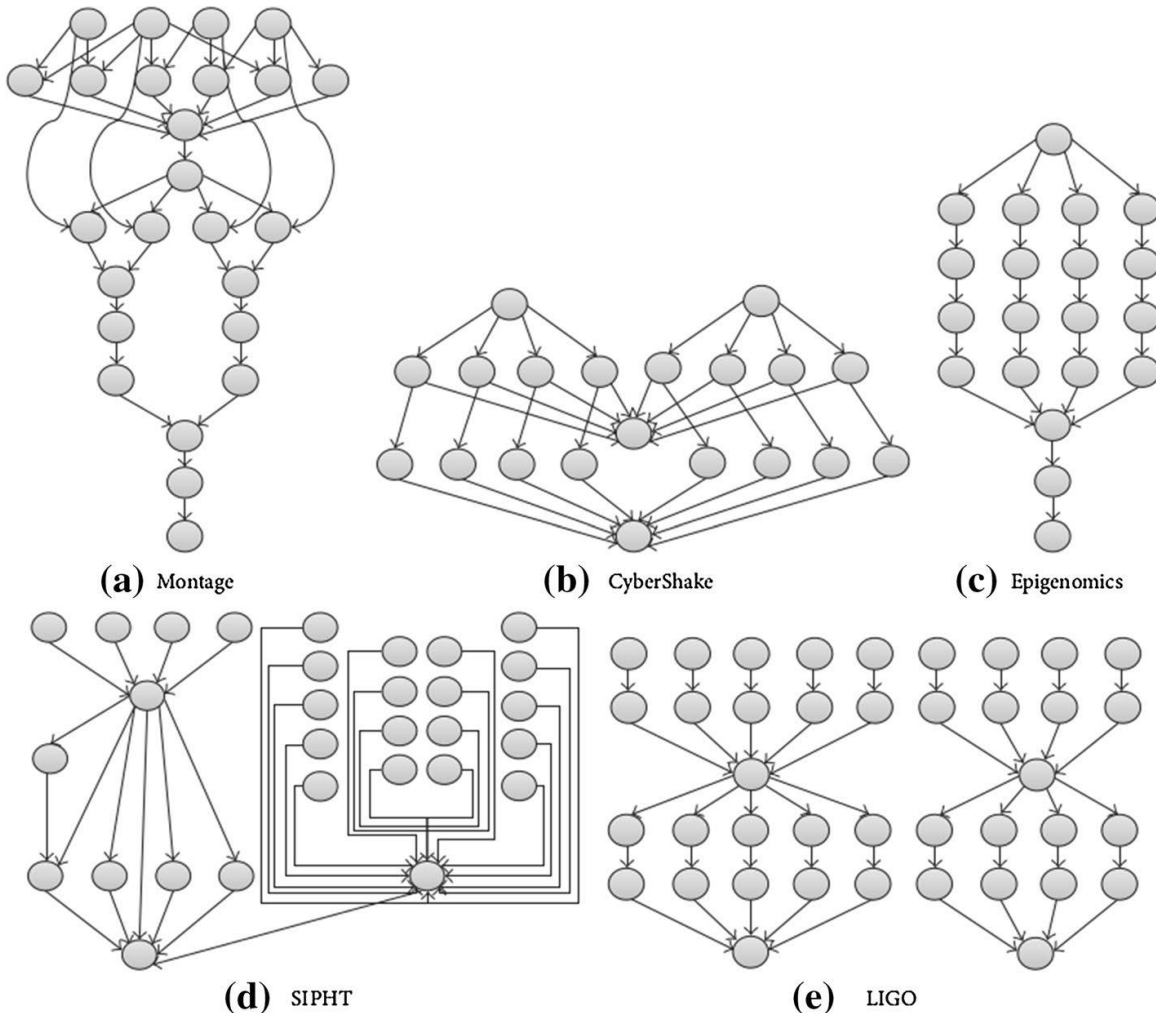
Fig. 2. The structural depiction of scientific workflows.
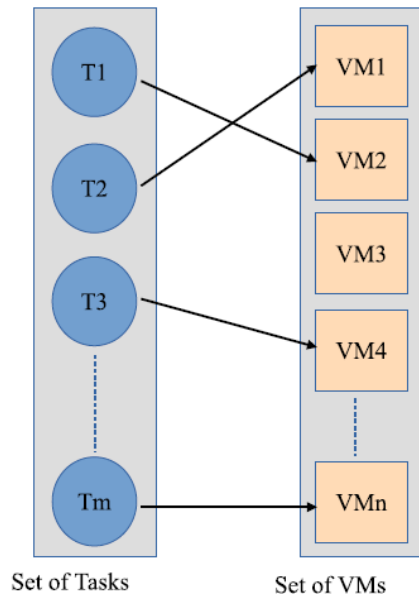
Fig. 3. Task mapping model.

## B. Fitness Function

The optimization algorithm aims to enhance specific parameters within the fitness function. In this context, we have employed two distinct fitness functions, labeled *F1* and *F2*, which are the focal points of optimization through the proposed algorithm. The initial fitness function, *F1*, encompasses a synthesis of the Total Execution Time (TET), whereas the subsequent fitness function, *F2*, is constructed from the Total Execution Cost (TEC). The precise formulations of TET and TEC are outlined in Eq. (1) and Eq. (5), respectively.

$$Fitness\ (F_1) = Total\ Execution\ Cost\ (TEC) \tag{1}$$

The total execution time, often referred to as the makespan, signifies the longest duration taken by tasks within the workflow to reach completion. But it quantifies the time necessary for accomplishing all tasks distributed among various VMs. The mathematical expression to compute the makespan of the workflow can be deduced from Eq. (2), where $CT_i$ symbolizes the completion time of task $T_i$ within the workflow. The completion time of a task encompasses its entire execution duration, and in cases where task dependencies exist, the waiting time of preceding tasks is also considered. The calculation of completion time is presented in Eq. (3). The waiting time for task $T_i$ is established as the utmost completion time among all predecessor tasks within the workflow, as delineated in Eq. (4). Furthermore, the execution time of task $T_i$ on $j^{th}$ VM can be evaluated using Eq. (5). Here, $SZ_{Task}$ signifies the size of task $T_i$, quantified in million instructions (MI), $Num\ (PE_j)$ represents the count of cores allocated to $j^{th}$ VM, and $PE_{Unit}$ denotes the magnitude of each core in Millions of Instructions per Second (MIPS).

$$TET_W = \max\{CT_t | 1,2,\dots,m\} \tag{2}$$

$$CT_i = \begin{cases} ET_i & if\ pred(T_i) = \emptyset \\ WK_i + ET_i & if\ pred(T_i) \neq \emptyset \end{cases} \tag{3}$$

$$WK_i = \begin{cases} 0 & if\ pred(T_i) = \emptyset \\ \max(CT_i) & if\ pred(T_i) \neq \emptyset \end{cases} \tag{4}$$

$$ET_{i,j} = \frac{SZ_{Task}}{Num(PE_j) \times PE_{Unit}} \tag{5}$$

Eq. (6) delineates the process for calculating TEC. The TEC for the $i^{th}$ VM is derived by calculating the disparity between the Least End Time (LET) and the Least Start Time (LST) of that specific VM. The cost associated with the $i^{th}$ VM, denoted as *C[i]*, is uniformly set at 1 across all VMs. To provide further clarity, Eq. (7) and Eq. (8) elucidate the mechanics behind computing the LET and LST, respectively. LET pertaining to the $i^{th}$ VM corresponds to the highest execution time among all tasks executed on that particular VM. Conversely, LST is determined as the minimum execution time of tasks in progress on the $i^{th}$ VM.

$$Total\ Execution\ Cost\ (TEC) = \sum_{i=0}^{VM} C[i] \times (LET[i] - LST[i] \tag{6}$$

$$LET[i] = \max(ET[i]) \tag{7}$$

$$LST[i] = \min(ET[i]) \tag{8}$$

## C. Proposed Algorithm

ACO algorithms harness a populace of ants to collaboratively address optimization challenges, navigating graphs to discover paths of minimal cost while upholding specific constraints. The behavior of these ants encompasses two distinct groups: a smaller ensemble lays down pheromone trails, while the other contingent diligently tracks these trails, reinforcing them while circumventing impulsive moves. As time elapses, the potency of these trails diminishes, leading to a waning allure for the ants. Let *G = (V, E)* symbolize the graph that underpins the optimization conundrum, where *V* denotes vertices and *E* signifies edges. On this graph, viable pathways correspond to potential resolutions for the optimization predicament. While in pursuit of the shortest path, the ants deposit pheromones along their journey, cultivating an enduring memory of the exploration process. Furthermore, heuristic values might be attributed to the graph's edges, derived from antecedent knowledge or real-time feedback, exerting influence over the ants' conduct.

The decision-making process of the ants is probabilistic in nature and relies on their memory, the constraints of the problem, and the ant-routing table, a localized data structure housing pheromone trails and heuristic values. Pheromone updates transpire through two distinct mechanisms: an online step-by-step update involving the deposition of pheromone by the ant while traversing an edge and an online delayed update, which involves adjusting pheromone trails after discovering a solution and retracing the path in reverse. Additional processes for updating pheromone trails include daemon actions and pheromone evaporation. Daemon actions, while discretionary, enable ants to execute actions that are beyond their individual capacities, often involving centralized actions. Pheromone evaporation entails a gradual reduction in the strength of

pheromone trails over time. This mechanism prevents the convergence toward suboptimal regions and promotes the exploration of novel areas within the graph.

**Algorithm. 1.** Generic ACO algorithm

Initialize

**While** stop criteria are not met **do**

   **For all** ant $a$ in $A$ **do**

     Position a in startNode

   End for

   Repeat

     **For all** ant $a$ in $A$ **do**

       Choose nextNode

       Pheromone$_{(currentNode,nextNode)}$+=Update

     End for

   **Until** every ant has a solution

   **For all** edge $e$ in $B$ **do**

     Pheromone$_e$+=Deposit

   End for

   **For all** edge $e$ in $E$ **do**

     Pheromone$_e$-=Evaporation

   End for

End while

Eq. (9) calculates the probability of an ant selecting a particular path. It depends on the number of pheromones$\tau_{i,j}$, present on the path between nodes $i$ and $j$ and the reverse of the distance ($\eta_{i,j}$) between these two nodes. The parameters $\alpha$ and $\beta$ are control parameters that influence the relative importance of pheromones and distance in the probability calculation.

$$p_{i,j}^{k} = \frac{[\tau_{i,j}]^{\alpha}[n_{i,j}]^{\beta}}{\sum_{l=j_i}[\tau_{i,l}]^{\alpha}[n_{i,l}]^{\beta}} \qquad (9)$$

The ants act like scouts, searching for food (appropriate service corresponding to user demands) in the environment. Once they find food, they return to their nests, dropping pheromones on the trails they have traversed. These

pheromones serve as a form of communication for other ants, indicating the quality of the path. The pheromone trail amount can either increase when ants deposit pheromone or decrease over time due to pheromone evaporation. Eq. (10) calculates the pheromone evaporation rate, where $1 - \omega$ is the pheromone declining rate.

$$\tau_{i,j} = (1 - \omega) \times \tau_{i,j} + \sum_{r=1} \Delta\tau^{r}i,j \qquad (10)$$

In the ACO algorithm, other ants tend to follow paths with a high amount of pheromone, as it indicates better solutions. There are two main approaches to updating the pheromone trails. The first approach involves selecting the best-so-far solutions (iteration best) and using them to update the pheromone matrices for each objective. These best solutions represent the most promising paths found so far in the search process. The second approach revolves around gathering and storing non-dominated solutions in an external set. Only the solutions in this non-dominated set are allowed to update the pheromone trails. Non-dominated solutions are those that cannot be improved in one objective without worsening at least one other objective. This approach helps maintain a diverse set of optimal solutions. Once the ants find food, they return to their nests, dropping pheromones on the trail they traveled. This pheromone serves as a signal for other ants to explore the same path, thus collectively reinforcing good solutions. Ants make local decisions based on their observations and the information available in their local environment. Instead of directly communicating with each other, ants use indirect forms of communication, which is referred to as "stigmergy." The pheromones left by ants' act as a form of stigmergic communication, guiding other ants to explore the most promising paths. Over time, the pheromones evaporate, which allows the algorithm to explore new areas and avoid convergence to sub-optimal solutions. The rate of pheromone evaporation is higher when returning to the nest takes a longer time, promoting the exploration of alternative paths. At intersections in the graph, each ant chooses one of the branches to continue its path. Ants tend to select shorter branches to return home faster, resulting in more pheromone accumulation on these shorter paths.
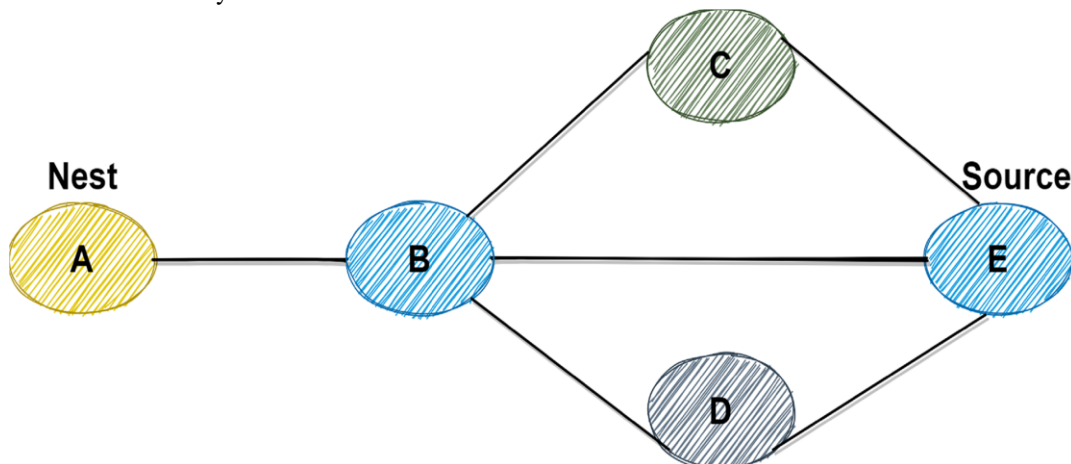


Fig. 4. Path selection by ants.

In the presented scenario (see Fig. 4), the ants encounter three paths: $A{\to}B{\to}C{\to}E$, $A{\to}B{\to}E$, and $A{\to}B{\to}D{\to}E$. Initially, due to the shorter distance, the shortest path $A{\to}B{\to}E$ will have a higher pheromone density. As the ants make their choices, they select paths based on the pheromone densities present on the branches. Consequently, most ants will opt for the shortest path, $A{\to}B{\to}E$. The main focus of the article is on the IACO algorithm for workflow scheduling in cloud computing. This algorithm combines the principles of ACO with a constrained optimization approach, which is suitable for solving single-objective discrete optimization problems. By leveraging pheromone communication and making local decisions based on observed pheromone densities, the IACO algorithm effectively guides ants to converge toward the shortest and most feasible paths in the search space.

Indeed, the IACO method exhibits several significant differences in each ant's behavior compared to the traditional ACO. The main distinctions between ACO and IACO are as follows:

- Pheromone functionality: In the ACO, the pheromones produced by ants serve only the function of attraction. Pheromones act as a positive signal, guiding ants to explore paths with higher pheromone densities. In contrast, the pheromones in the IACO method serve a dual purpose. Besides attraction, they also act as a form of repulsion. This repulsive nature of pheromones helps to alleviate the pressure on certain paths or nodes. It discourages ants from over-converging on a specific route or node.

- Role of nodes: In the ACO, nodes do not directly influence the algorithm. The focus lies primarily on paths and the pheromones present on those paths as important parameters.

- IACO Method: In the IACO, nodes play a significant role as influencing parameters. They store the number of pheromones present. If the pheromone count exceeds a specific value, the node acts as a blockade, preventing other ants from passing through it. This approach is designed to reduce pressure on certain nodes and is directly linked to the pheromone value.

- Consideration of route capacity: ACO does not explicitly consider the maximum capacity on a path when updating pheromones. In the IACO, the pheromone's evaporation process takes into account both the length of the route and the maximum capacity of the route. This consideration helps to ensure that the algorithm avoids routes that may become congested due to excessive pheromones.

These differences in behavior and parameterization between ACO and IACO allow the IACO method to address complex optimization problems more effectively, especially in scenarios where path congestion and capacity constraints are crucial considerations. By combining both attractive and repulsive properties of pheromones and incorporating node-based mechanisms, IACO offers an enhanced approach for finding optimal or near-optimal solutions in constrained optimization problems.

## IV. PERFORMANCE EVALUATION

In the experiments conducted to verify the performance of the proposed method, we used the WorkflowSim toolkit. The implementations of strategies were implemented in Java and run on a computer with an Intel Core i5 processor running at 2.8 GHz and equipped with 4 GB of RAM. The WorkflowSim toolkit is an extension of CloudSim, designed specifically to simulate an environment for executing scientific workflows. In pursuit of an equitable comparison of outcomes, the simulations involving the proposed approach and other established methods were orchestrated under identical conditions. This systematic parity in experimentation conditions serves to objectively gauge the performance and efficacy of the proposed approach in contrast to alternative methodologies. The experimental trials were conducted utilizing three distinct real-world workflow applications, each hailing from diverse scientific domains. Noteworthy among these is the Montage workflow applied within the realm of astronomical physics. Furthermore, the Cybershake workflow was harnessed to analyze earthquake hazards, while the Ligo workflows were instrumental in the quest for gravitational wave detection.

The configuration of VMs is based on the specifications of Amazon EC2 instances, which are commonly used in cloud computing environments. Within the simulation model, it is assumed that the storage capacity of every VM is generously sufficient to host all the allocated tasks. Nonetheless, the mean bandwidth linking distinct virtual machines exhibits variability across three distinct scenarios: 5 Gb/s, 10 Gb/s, and 25 Gb/s. The variation in bandwidth represents different network capacities and performance levels that can affect task execution and communication between VMs. Additionally, the virtual machine preparation time is taken into consideration during the simulations. This preparation time represents the overhead required to set up and configure a VM before it can start executing tasks. The temporal interval required for VM preparation is modeled to fluctuate within the range of 1 second to 1.5 seconds. During the evaluation process of the proposed IACO algorithm, a comprehensive comparison is conducted against three alternative algorithms: standard ACO, FR-MOS, and PEFT-ACO algorithms.

In the first series of experiments, the algorithms were evaluated independently for each objective, i.e., cost and makespan. The experiments were performed on three different types of workflows: Montage, Cybershake, and Ligo, with varying numbers of tasks (100 and 300). The results averaged over 100 executions for each workflow type, are presented in Table I. It is observed that the traditional ACO algorithm performs poorly in both the total cost and makespan across all three workflow types. On the other hand, the IACO algorithm is superior to both PEFT-ACO and FR-MOS regarding cost and makespan across all workflow types. The discernible distinction in performance is especially pronounced with regard to makespan. This indicates that IACO is more efficient and effective in exploring the solution space and finding globally optimal or near-optimal solutions. Fig. 5 and Fig. 6 provide visualizations of the average results for makespan and cost when the number of tasks is set to 500.

TABLE I.  OBTAINED RESULTS FOR COST AND MAKESPAN

| Workflow | Tasks count | IACO | | FR-MOS | | PEFT-ACO | | ACO | |
|---|---|---|---|---|---|---|---|---|---|
| | | Cost ($/h) | Make span (s) | Cost ($/h) | Make span (s) | Cost ($/h) | Make span (s) | Cost ($/h) | Make span (s) |
| Montage | 100 | 14.1 | 468.2 | 15.9 | 614.7 | 25.6 | 625.8 | 52.2 | 654.3 |
| | 300 | 9.2 | 584.7 | 13.8 | 679.4 | 20.1 | 693.5 | 30.1 | 708.3 |
| Cybershake | 100 | 21.8 | 489.5 | 40.7 | 513.7 | 57.7 | 578.5 | 70.2 | 695 |
| | 300 | 19.8 | 627.1 | 32.1 | 659.4 | 43.9 | 701.8 | 53.7 | 872.4 |
| Ligo | 100 | 31.5 | 559.1 | 46.9 | 609.5 | 69.7 | 695.8 | 78.7 | 710.8 |
| | 300 | 26.9 | 697.4 | 42.8 | 823.4 | 64.4 | 888.1 | 77.2 | 896.7 |
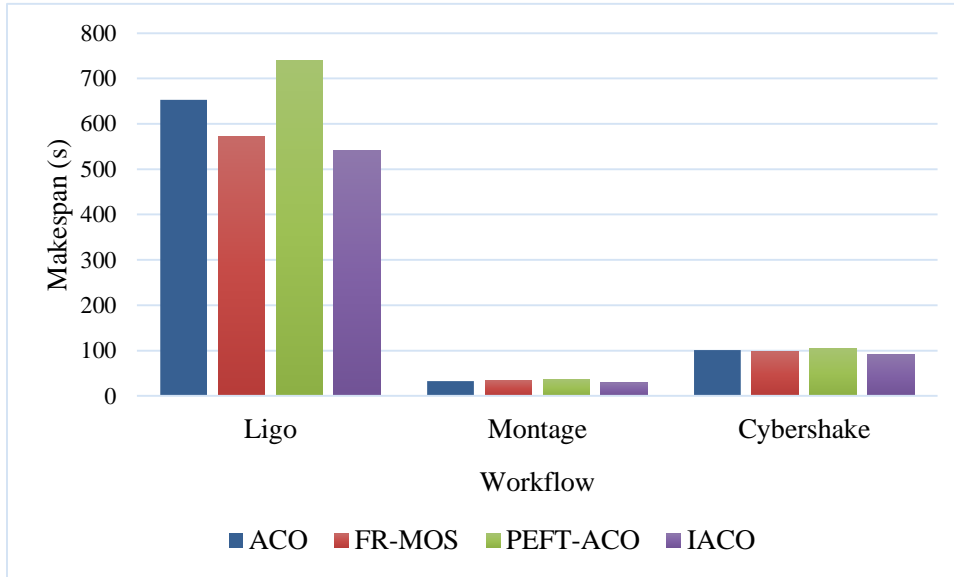


Fig. 5.  Makespan comparison.
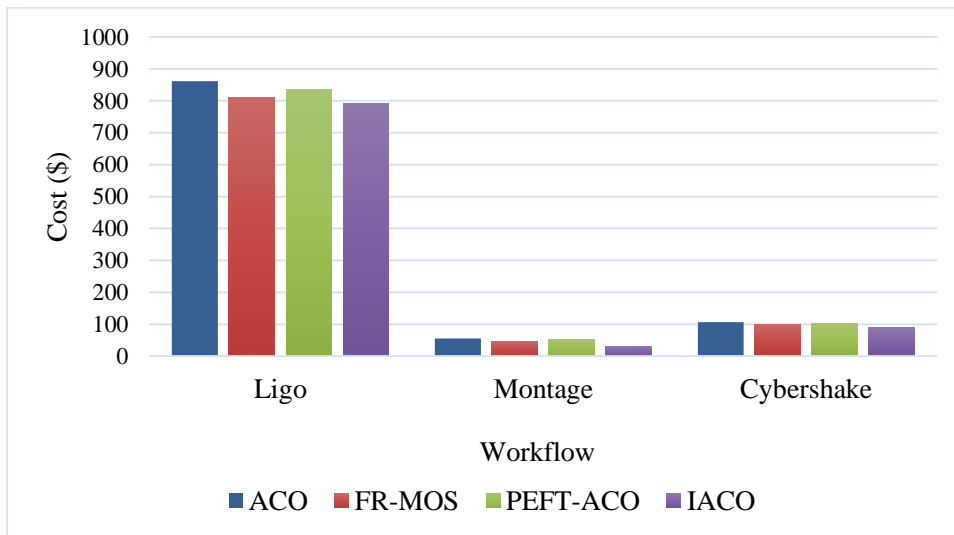


Fig. 6.  Cost comparison.

## V.  CONCLUSION

Cloud computing has emerged as a revolutionary concept in the field of distributed systems, providing efficient and scalable solutions for high-performance and distributed computing needs. Its dynamic nature, virtual resource provisioning, and pay-per-use model have contributed to its widespread popularity among organizations and research laboratories. In this context, workflow scheduling plays a crucial role in optimizing the execution of applications in cloud environments. Workflows model processes as a sequence of steps, and scheduling involves assigning each task of the workflow to an appropriate processing resource while adhering to specific workflow rules and constraints. This paper proposed a novel

workflow scheduling approach called Inverted ACO (IACO). The IACO algorithm leverages the principles of the ACO algorithm but introduces unique modifications to improve its performance in cloud-based workflow scheduling scenarios. The experiments were carried out utilizing instances from the Amazon EC2 cloud platform, encompassing three distinct real-world workflow types originating from various scientific domains.

In the comparative analysis, IACO was assessed against established methodologies in the field, namely standard FR-MOS, PEFT-ACO, and ACO algorithms. The results of the experiments show that IACO outperforms all other algorithms in most tests, particularly in terms of the trade-off between makespan and cost. This work could explore how the IACO algorithm adapts dynamically to varying cloud environments, taking into account factors like workload fluctuations and cloud structure diversity. Additionally, exploring the integration of IACO with machine learning or other metaheuristic approaches could expand its efficiency and applicability. Moreover, investigating the scalability of IACO in hybrid cloud settings or its adaptability to real-time workflow changes could significantly advance its practical implementation. Furthermore, assessing the robustness of IACO against various cloud constraints, including resource limitations or network latency, would contribute to a more comprehensive understanding of its performance under diverse cloud scenarios.

## REFERENCES

[1] B. Pourgheble, A. A. Anvigh, A. R. Ramtin, and B. Mohammadi, "The importance of nature-inspired meta-heuristic algorithms for solving virtual machine consolidation problem in cloud environments," Cluster Computing, pp. 1-24, 2021.

[2] M. Hosseinzadeh et al., "A Hybrid Service Selection and Composition Model for Cloud-Edge Computing in the Internet of Things," IEEE Access, vol. 8, pp. 85939-85949, 2020.

[3] R. K. Tiwari and R. Kumar, "G-TOPSIS: a cloud service selection framework using Gaussian TOPSIS for rank reversal problem," The Journal of Supercomputing, vol. 77, no. 1, pp. 523-562, 2021.

[4] S. K. Panda and P. K. Jana, "An energy-efficient task scheduling algorithm for heterogeneous cloud computing systems," Cluster Computing, vol. 22, no. 2, pp. 509-527, 2019.

[5] V. Sundararaj, "Optimal task assignment in mobile cloud computing by queue based ant-bee algorithm," Wireless Personal Communications, vol. 104, no. 1, pp. 173-197, 2019.

[6] X. Wei, "Task scheduling optimization strategy using improved ant colony optimization algorithm in cloud computing," Journal of Ambient Intelligence and Humanized Computing, pp. 1-12, 2020.

[7] B. Cao, Z. Sun, J. Zhang, and Y. Gu, "Resource allocation in 5G IoV architecture based on SDN and fog-cloud computing," IEEE Transactions on Intelligent Transportation Systems, vol. 22, no. 6, pp. 3832-3840, 2021.

[8] P. Behrouz, H. Vahideh, and A. A. Aghaei, "Service discovery in the Internet of Things: review of current trends and research challenges," Wireless Networks, vol. 26, no. 7, pp. 5371-5391, 2020.

[9] A. Sheeba and B. Uma Maheswari, "An efficient fault tolerance scheme based enhanced firefly optimization for virtual machine placement in cloud computing," Concurrency and Computation: Practice and Experience, vol. 35, no. 7, p. e7610, 2023.

[10] H. Vahideh, P. Behrouz, P. K. A. Asghar, and A. Ghaffari, "Exploring the state-of-the-art service composition approaches in cloud manufacturing systems to enhance upcoming techniques," The International Journal of Advanced Manufacturing Technology, vol. 105, no. 1-4, pp. 471-498, 2019.

[11] V. Hayyolalam, B. Pourgheble, M. R. Chehrehzad, and A. A. Pourhaji Kazem, "Single-objective service composition methods in cloud manufacturing systems: Recent techniques, classification, and future trends," Concurrency and Computation: Practice and Experience, vol. 34, no. 5, p. e6698, 2022.

[12] B. Pourgheble and V. Hayyolalam, "A comprehensive and systematic review of the load balancing mechanisms in the Internet of Things," Cluster Computing, pp. 1-21, 2019.

[13] P. He, N. Almasifar, A. Mehbodniya, D. Javaheri, and J. L. Webber, "Towards green smart cities using Internet of Things and optimization algorithms: A systematic and bibliometric review," Sustainable Computing: Informatics and Systems, vol. 36, p. 100822, 2022, doi: https://doi.org/10.1016/j.suscom.2022.100822.

[14] S. N. H. Bukhari, J. Webber, and A. Mehbodniya, "Decision tree based ensemble machine learning model for the prediction of Zika virus T-cell epitopes as potential vaccine candidates," Scientific Reports, vol. 12, no. 1, p. 7810, 2022.

[15] T. Gera, J. Singh, A. Mehbodniya, J. L. Webber, M. Shabaz, and D. Thakur, "Dominant feature selection and machine learning-based hybrid approach to analyze android ransomware," Security and Communication Networks, vol. 2021, pp. 1-22, 2021.

[16] B. M. Jafari, M. Zhao, and A. Jafari, "Rumi: An Intelligent Agent Enhancing Learning Management Systems Using Machine Learning Techniques," Journal of Software Engineering and Applications, vol. 15, no. 9, pp. 325-343, 2022.

[17] M. Sadi et al., "Special Session: On the Reliability of Conventional and Quantum Neural Network Hardware," in 2022 IEEE 40th VLSI Test Symposium (VTS), 2022: IEEE, pp. 1-12.

[18] J. Webber, A. Mehbodniya, Y. Hou, K. Yano, and T. Kumagai, "Study on idle slot availability prediction for WLAN using a probabilistic neural network," in 2017 23rd Asia-Pacific Conference on Communications (APCC), 2017: IEEE, pp. 1-6.

[19] R. Singh et al., "Analysis of Network Slicing for Management of 5G Networks Using Machine Learning Techniques," Wireless Communications and Mobile Computing, vol. 2022, 2022.

[20] S. Habib, S. Aghakhani, M. G. Nejati, M. Azimian, Y. Jia, and E. M. Ahmed, "Energy management of an intelligent parking lot equipped with hydrogen storage systems and renewable energy sources using the stochastic p-robust optimization approach," Energy, p. 127844, 2023.

[21] S. Mahmoudinazlou, A. Alizadeh, J. Noble, and S. Eslamdoust, "An improved hybrid ICA-SA metaheuristic for order acceptance and scheduling with time windows and sequence-dependent setup times," Neural Computing and Applications, pp. 1-19, 2023.

[22] A. Choudhary, I. Gupta, V. Singh, and P. K. Jana, "A GSA based hybrid algorithm for bi-objective workflow scheduling in cloud computing," Future Generation Computer Systems, vol. 83, pp. 14-26, 2018.

[23] S. Elsherbiny, E. Eldaydamony, M. Alrahmawy, and A. E. Reyad, "An extended intelligent water drops algorithm for workflow scheduling in cloud computing environment," Egyptian informatics journal, vol. 19, no. 1, pp. 33-55, 2018.

[24] G. Ismayilov and H. R. Topcuoglu, "Neural network based multi-objective evolutionary algorithm for dynamic workflow scheduling in cloud computing," Future Generation computer systems, vol. 102, pp. 307-322, 2020.

[25] S. Mangalampalli, G. R. Karri, and G. N. Satish, "Efficient Workflow Scheduling algorithm in cloud computing using Whale Optimization," Procedia Computer Science, vol. 218, pp. 1936-1945, 2023.

[26] M. Zeedan, G. Attiya, and N. El-Fishawy, "Enhanced hybrid multi-objective workflow scheduling approach based artificial bee colony in cloud computing," Computing, vol. 105, no. 1, pp. 217-247, 2023.

# Measuring Surroundings Awareness using Different Visual Parameters in Virtual Reality

Fatma E. Ibrahim[1], Neven A. M. Elsayed[2], Hala H. Zayed[3]

Faculty of Computers and Artificial Intelligence, Benha University, Benha, Egypt[1,2,3]

Faculty of Engineering, Egypt University of Informatics (EUI), Cairo, Egypt[3]

*Abstract*—Due to the popularity of digital games, there is a growing interest in using games as therapeutic interventions. The ability of games to capture attention can be beneficial to distract patients from pain. In this paper, we investigate the impact of visual parameters (color, shapes, and animation) on users' awareness of their surroundings in virtual reality. We conducted a user study in which experiments included a visual search task using a virtual reality game. Through the game, the participants were asked to find a target among distraction objects. The results showed that the different visual representations of the target among distraction objects could affect the users' awareness of their surroundings. The least awareness of the surroundings occurred when the target and distractors shared similar features. Further, the conjunction of low similarity between distractors-distractors and high similarity between target-distractors provided less awareness of the surroundings. Additionally, results revealed that there is a strong positive correlation between search time and awareness of the surroundings. Less awareness of the surroundings while playing a game implies that users are positively engaged in that game. These results offered a set of criteria that can be applied to future virtual reality interventions for medical pain distraction.

*Keywords*—*Virtual reality; visual distraction; attention; awareness*

## I. Introduction

Game playing was recognized as the most attractive activity for individuals all over the world. The success of games is highly dependent on their ability to keep their players engaged [1]. Despite some of the negative aspects of playing games, there is growing research demonstrating the positive effects that game playing can provide. If games succeed to activate users' attentional engagement and motivation, they can be of valuable therapeutic benefits [2]. Playing games offers a promising non-pharmacological distraction technique for pain control by diverting attention away from painful stimuli [3]. The logic behind distraction is that pain requires attention and humans have limited information-processing resources [4]. Therefore, the more attentional resources a distraction intervention consumes, the fewer resources are available for pain perception [3]. The research work conducted by [5] [5] highlights that high attentional engagement during games demonstrates a significant analgesic effect on pain distraction.

Distraction interventions can engage one or more sensory modalities. Each modality could have an impact on the distraction level to attract focused attention. In the range of sensory modalities, vision is the most important in its capacity and utility in terms of perception [6]. Besides, distraction using visual tasks was confirmed to significantly reduces pain compared to other modalities [7], [8]. Numerous studies demonstrated that

the majority of processing information comes from the visual modality *(visual dominance)* [9]. A wide range of research supported that our vision captures the most percentage of our attentional resources [10]. Recently, virtual reality (VR) becomes one of the major tools that affect visual perception by offering a highly immersive and tangible interaction experience [11]. Experimental research showed that immersive environments build strong user engagement compared to screen-based environments [11]. VR technologies provide a higher degree of presence through increased interactivity and hence increase the user's attention to the virtual environment [11]. The unique characteristics of VR encouraged researchers to conduct numerous studies, [12], [13], to investigate the effect of VR as a non-pharmacological tool for pain management.

We believe that understanding the visual parameters affecting humans' awareness of their surroundings in VR is valuable. Less awareness of the surroundings increases engagement and immersion in the visual activity. High engagement demands a greater amount of user's focused attention. This is critical for many applications such as game-based learning [14], engagement in games [15], and pain distraction [16]. Tasks that require subjects to detect a particular target among distractors gained a great interest in the research of vision and attention [17]. The results of these tasks depend on the features of the target and distractors. Different features might have different capabilities to guide users' attention in a given task [17]. The efficiency of a visual search can be assessed based on changes in performance such as search time or accuracy [17]. Many studies [18], [19], have presented theories to discuss the factors that affect visual search efficiency in 2D, such as the *feature integration theory* and the *similarity theory*.

In this paper, we provide a user study to measure the impact of different visual parameters on users' awareness of their surroundings and task search time in VR. Experiments in this study focus on the principle of visual search using a simple VR game. Numerous studies proved that using the illusion of VR significantly reduces the perception of pain. Although, to our knowledge, no studies were conducted to determine the impact of visual parameters that affect the users' awareness of their surroundings. The less awareness of the surroundings implies that the VR intervention engages much of a user's attentional capacity. This is valuable, especially when developing VR interventions for pain distraction. Results from this study will be considered in designing future VR interventions for medical pain distraction.

Through the following sections, this paper discusses the background of VR distraction for managing pain in Section II. Then, Section III presents the conducted user study. Further-

more, in Section IV we summarize the main findings of the study. Finally, the discussion and conclusion are included in Sections V and VI, respectively.

## II. BACKGROUND

This section discusses in detail the related work of using VR distraction for pain management. Section II(A) provides some background on VR technology. Section II(B) discusses some applied VR research for pain distraction and reduction.

### A. Virtual Reality

With advances in wearable technology, VR became popular across various industries due to its ability to engage users in a multisensory environment. There are several definitions of VR, but the most appropriate one "it is defined as a real or simulated environment in which a user experiences telepresence". This definition is chosen as it describes VR without any implications of technology [20]. VR offers a combination of three effects: *1) Fully immersion*, users wear a headset that visually isolates them from the real world, *2) Stereoscopic vision*, the simulation of the real world in three dimensions, and *3) Motion capture*, allows the tracking of head position and controllers with three or six degrees of freedom [21]. These effects enable VR to provide users with a unique visualization tool to explore, manipulate, and interact with their data.

VR is unique in that it allows a multisensory experience that involves visual, auditory, and tangible senses [22]. The VR characteristics of immersion, presence, and interactivity provide users with a greater sense of engagement. These three factors may subsequently prompt better distraction outcomes from a VR intervention via increased engagement. Presence describes the subjective experience of being in one place or environment, even when one is physically situated in another [23]. There are two points of view for immersion definition; the first is based on the state of mind (feeling caught up in and absorbed by the virtual world) and the second is based on the technological capability of a VR system (1)Fully immersive, using a head-mounted display (HMD), (2)Semi-immersive, using large projection screens, (3)Minimal-immersive, using window-based display) [24]. Interactivity describes the degree to which users can influence the content of the virtual environment [24]. According to [25], growing improvements in hardware and software make VR technology more affordable for the scientific and commercial community.

### B. Virtual Reality Distraction

Various studies have shown that VR distraction is more effective in reducing pain and anxiety than typical distraction techniques such as deep breathing, listening to music, watching a favorite video, and hypnosis [13]. The last decade has witnessed exponential growth in using VR interventions for pain management with encouraging results that recommend VR distraction to enhance treatment outcomes [26]. Numerous studies were conducted to investigate the effectiveness of VR distraction in reducing different types of pain. Research in this area [16], [27], indicates that VR is a promising adjunct for controlling acute and chronic pain.

Patients with severe burn injuries frequently experience extreme pain related to the injury itself or its wound care procedures. VR distraction provided a strong non-opioid pain control technique for both pediatric and adult burn patients even in the Intensive Care Unit [28]. Also, adding VR to the rehabilitation program of pediatric burn patients had a significant effect on decreasing pain [29]. The main finding from these studies is that VR significantly reduces pain and other uncomfortable symptoms experienced by burn patients [30]. Also, the findings of the chronic pain studies supported the efficacy of VR distraction. Patients reported a significant decrease in pain ratings when using VR interventions compared to the control condition [31]. However, the studies focused on the area of using VR with chronic pain were few [13], and further investigations are needed to ensure its feasibility.

Moreover, VR succeeded to offer a powerful distraction tool for patients who suffer from cancer pain. Cancer patients experience pain associated with the disease itself and/or pain caused by examinations and treatments such as chemotherapy. Several studies showed that VR interventions are effective in reducing pain and other chemotherapy-related symptoms in both adult and pediatric patients suffering from different types of cancer [26], [32]. Patients receiving VR during their chemotherapy session reported less time thinking about pain and also an underestimation of the treatment session duration [33]. VR distraction can help cancer patients accept and tolerate the treatment procedures and hence accelerate the recovery process.

Further to the above category of studies that investigated the efficacy of VR distraction, other studies investigated whether VR distraction will provide a larger analgesic effect when used repeatedly during treatment sessions [28], [34]–[36]. Results indicated that VR efficacy did not diminish with repeated use and pain intensity levels dropped significantly. Previous research, as indicated by both [34] and [36], suggested that receiving VR for a longer treatment duration is more effective than the shorter duration.

Moreover, few studies have investigated the impact of low-cost VR technology on pain tolerance [37], [38]. For both studies, participants were suffering from severe burn injuries and results showed that low-cost VR technology succeeded to achieve a promising pain reduction level. This key finding will open the door to conducting further research to generalize using cost-effective technology with many more patients and different types of pain. Finally, VR interventions can also be used effectively to distract young children aged less than four years during their wound care procedure [39]. This study used a projector-based VR system and the results indicated that VR significantly reduced children's acute pain.

Results from the scientific literature support the adjunctive use of VR distraction for pain management. However, it remains unclear what is the impact of different visual parameters such as color, shapes, and animation on users' awareness of their surroundings. Understanding the impact of such parameters on the awareness of the surrounding is valuable in developing powerful VR therapeutic interventions. To this aim, we conducted a study that included a VR game where players searched for a target among distractors. One study has investigated the impact of color congruency on task search time in VR. This study measured the search task performance when target and distractors were varied

concerning congruency [40]. Moreover, the study examined the impact of using a flanker item as a visual distraction from completing task flow. Participants were asked to search for daily items on a virtual kitchen countertop and ignore flanker items. Results indicated that the search time became longer when the target and distractors shared color.

Regarding 2D applications, many studies examined the impact of visual representations of the target and distractors on task search time. Treisman et al. [18] provided a framework that explained the hypotheses of the feature integration theory. This theory hypothesized that the search task will proceed slowly when the target and distractors share features. The theory suggested that the human visual system maintains a set of feature maps for different visual attributes (such as color or shape). When the target has a unique feature, one feature map will be accessed and hence leading to a fast response time. Another research work suggested that the amount of difference between the target-distractors and distractors-distractors will affect the search time [19]. This theory hypothesizes that if the "target-distractors" similarity is high, then search efficiency decreases and search time increases. Besides, if the "distractors-distractors" similarity is low, then search efficiency decreases and search time increases.

These researches showed that the presented visual features could significantly affect users' focus of attention and engagement in search tasks. However, one important gap in the literature on virtual reality analgesia is that no studies explored the impact of different visual parameters such as color, shapes, and animation on users' awareness of their surroundings. To address this gap, we performed a user study to determine the impact of these visual parameters on users' awareness of their surroundings and task search time. Moreover, we are also interested in exploring whether there is a correlation between task search time and awareness of the surrounding. The results from this study will help to develop effective VR interventions that engage most of the patient's attention and hence feel less pain.

## III. METHODS

This study was designed to help in developing a future VR game for medical pain distraction. To provide more distraction effects, it is valuable to determine the impact of different visual parameters on users' awareness of their surroundings while in VR. We found that visual components such as color, shape, and animation are commonly included in any digital game. Accordingly, we focused on determining the impact of these visual components on users' awareness of their surroundings. Experiments in this study focus on the principle of visual search using a simple VR game. We examined the impact of different visual representations of the target and distractors on the search performance and awareness of the surroundings.

### A. User Study

The study used a within-subject design where each participant experienced different conditions. These conditions varied with respect to some visual parameters such as color, shape, and animation. The participants were asked to perform a primary visual task, finding a target cube among distraction objects as fast as possible. Moreover, external disruptions (audio or vibration) were generated randomly while performing the search task. These disruptions were used to measure their awareness of the surroundings without affecting the completion of the primary task. The number of these disruptions was fixed among participants, but the order of them was randomized. Each condition consisted of twenty-five trials and had a duration of about three minutes. At the end of each condition, a compulsory break time was offered. During the break, each participant had to fill in a simple questionnaire that asked about the time duration and the observed disruptions - e.g., "How long did you feel the condition take?", and "Did you observe any disruption?".

If they answered "yes" to the latter question, they have to provide which types occur and the number of their occurrence frequency. The experiment took around forty-five minutes per participant including breaks. For all conditions, we recorded the completion time and the generated disruptions. Through the study, we examined task completion time and disturbance awareness for each of the study's conditions. We measured the awareness and illusion errors that were reported by the participants. Awareness error is the number of missed disruptions, while illusion error is the number of disruptions that never happened. These data were collected to measure the participants' awareness of the surrounding environment.

### B. Participants

A total of 31 undergraduate students (19 females) (12 males) aged (18-24) years participated in the study. Participants were recruited via a university announcement for voluntary inclusion in the study. All participants were eligible with respect to the criteria determined for the study (had normal visual and normal color vision). Five participants were excluded as they suffered from VR-induced motion sickness. So, a total of 26 healthy participants were included in the study analysis. Informed consent for the publication of identifying information/images in an online open-access platform and for participation in the study was provided by all participants before the experiment. The study was approved by the ethical committee in the Faculty of Computers and Artificial Intelligence, Benha University. All methods were carried out in accordance with relevant guidelines and regulations. The flow of participants is shown in the flow diagram (see Fig. 1).

### C. Equipment

We carried out the experiments of the study using a controlled room. Participants delivered the VR experience using a *Xiaomi MI VR* headset with a Samsung Galaxy Note3 phone and a handheld controller as an interaction device. We used this head-mounted display to be able to use a variety of mobile phones. The Samsung Galaxy Note3 phone was attached to the HMD and was used for recording the completion time of the condition. Another mobile phone was used and attached to the participant's left arm. This phone was also used to generate random disruptions and save them. The participants were able to look around and navigate the virtual environment using their heads. The VR application was developed using the Unity engine and the Android application using Android Studio. The condition started once the participant wore the HMD and ended when the twenty-five trials ended. Fig. 2 shows the hardware components used in the experiment besides one of the participant's trials.
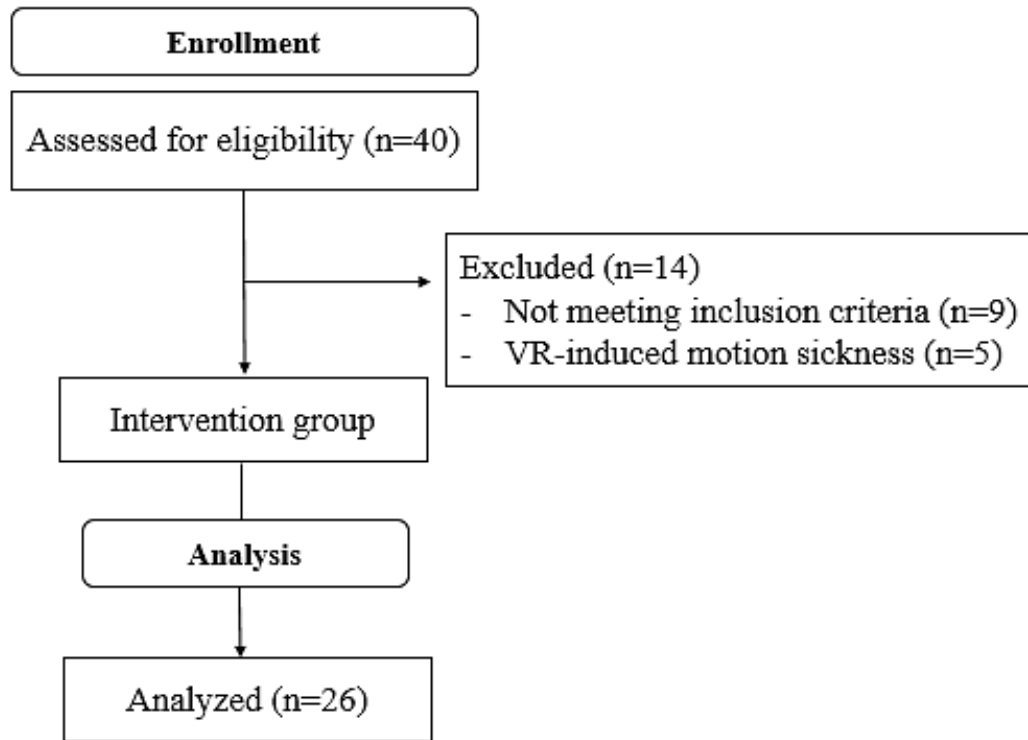
Fig. 1. Flow of participants.



Fig. 2. Experiment hardware components (left), and a participant trial (right).

### D. Stimuli

Participants were situated in a full virtual closed room surrounded by a number of distractive objects. There was only one real target cube which was always spawned randomly at the eye level of the user. The size of the objects was scaled according to their distance away from the camera's location (size was around 10 % of the display width and 22 % of its height). The distractive objects were spawned at fixed random locations within the room. Colors were defined by the following RGB values: target (R=0, G=255, B=118), in conditions 2 and 5 distractor's red color (R=255, G=0, B=0), in conditions 3, 4, and 6 the colors of the cubes were generated randomly while spheres in condition 6 used the same target color. The environment was populated with 20 distractive objects. The experiment took around forty-five minutes per participant. Each participant performed 150 trials: 6 conditions × 25 trials per condition.

### E. Study Design

The study was carried out in immersive VR and included six different conditions with the same task. The participants were asked to find a target object in the presented VR condition. Each condition included a different visual representation of the target and distraction objects, which is our study's independent variable. This differentiation among conditions is used to investigate the different visual parameters and their impact on users' awareness of their surroundings. The following are our study's conditions:

1) Condition1: Single-cube.
2) Condition2: One-color cubes.
3) Condition3: Multi-color cubes.
4) Condition4: Animated cubes.
5) Condition5: Spheres.
6) Condition6: Cubes-spheres.

All conditions included one target green cube along with other distraction objects spheres or cubes. The order of exploring the conditions was randomized among the participants. We previously conducted a pilot study to determine the best visual design for the conditions. Also, the pilot study helped us to determine the break time duration which was set to five minutes.

Fig. 3 shows our study's six conditions, where the visual representation of the target and distraction objects varied between them. Fig. 3(a) shows "Condition1" that included the target green cube only with no distraction objects. Fig. 3(b) shows "Condition2" with one-color distraction objects. Participants were asked to find the target green cube which was allocated randomly with the fixed distraction red cubes. Fig. 3(c) shows "Condition3" with a fixed multi-color distraction objects. The participants had to find the target green cube out of the multi-color presented cubes. Fig. 3(d) shows "Condition4" with animated multi-color cubes as distraction objects. Condition4 included an extra effect which was animation. Fig. 3(e) shows "Condition5" in which participants had to find the target green cube hidden between fixed red spheres. Condition5 included different shapes as distraction objects. Fig. 3(f) shows "Condition6" in which participants had to find the target green cube which was surrounded by fixed one-color spheres (the same target color) and fixed multi-color cubes.

The participants were asked to complete the six conditions. The completion time and the generated disruptions were recorded for each condition by the application. The *completion time* was automatically recorded from the start of the condition till the participant finished the twenty-five trials. The completion time represented the total time taken to finish the condition. Moreover, we recorded the response time taken to find the target in each trial. We calculated the *search time* for the condition as the average of the twenty-five trials' response time. The completion time was saved on the mobile attached to the HMD, while the generated disruptions were saved on the other mobile phone. On the other hand, the estimated time and errors were reported by the participants via the questionnaire that was filled out after each condition. All of the data was recorded and transcribed to a computer spreadsheet for later analysis.

### F. Procedure

Prior to running the study, we had explained many rules and cautions to the participants. We told them to take off the HMD and stop running the condition if they felt any VR-induced motion sickness during their running. We showed an example display of the conditions to explain how to play. The participants heard the audio disruptions and felt the vibrations to get familiar with them. We had two types of audio disruptions (*ringtone and beep*) and two types of vibrations that varied in duration *(short: one second and long: three seconds)*. After getting ready the participant wore the HMD, hold the handheld controller, and attached the other mobile phone to his/her left arm to start the condition. The participants used the handheld controller to press on the target green cube when found.

The primary purpose of the study was to determine the impact of different visual parameters on users' awareness of their surroundings in VR. The conditions varied according to many parameters such as color, shape, and animation. The main task was to search for the green target cube and find it as fast as possible. When the target fell into the participant's view, he/she focused the cursor of the handheld controller on the target and place a single click. Finding the target indicated the end of a trial and the start of a new one. After the click, the target disappeared and a new target object was randomly located in another location within the same room. Through each condition, the mobile attached to the participant's left arm randomly generated *four* disruptions. The type and occurrence frequency of these four disruptions were used to measure both the awareness and illusion errors. We supported different types of disruption to measure the participants' awareness of the surrounding environment. The number of disruptions (four) was fixed among conditions and participants. After twenty-five trials, the current condition was ended and the compulsory break time must be taken.

During break time, the participants were offered to take off the HMD and were asked to fill out the user-experience questionnaire. The participants were asked to report the estimated time duration of the condition in minutes. Also, they were asked to report the observed disruptions that occurred during running the condition. After the break time, the participants return back to continue running the study and repeat the same procedure with a new condition. Each participant completed a block of six conditions. The order of experiencing the conditions was randomized among the participants.

## IV. EXPERIMENTAL RESULTS

Analyses of the sample data (N = 26) were conducted using IBM SPSS Statistics v25. For all analyses, an alpha level of 0.05 was used unless otherwise specified.

### A. Completion Time

We ran the study to measure if the visual parameters affect the task completion time or/and users' awareness of the surroundings in VR. We recorded the data as we calculated the time difference values by subtracting the completion time (automatically recorded) from the estimated time (reported by the participant). This time difference was used to generate the *less_than* and *greater_than* values. *Less_than* indicated
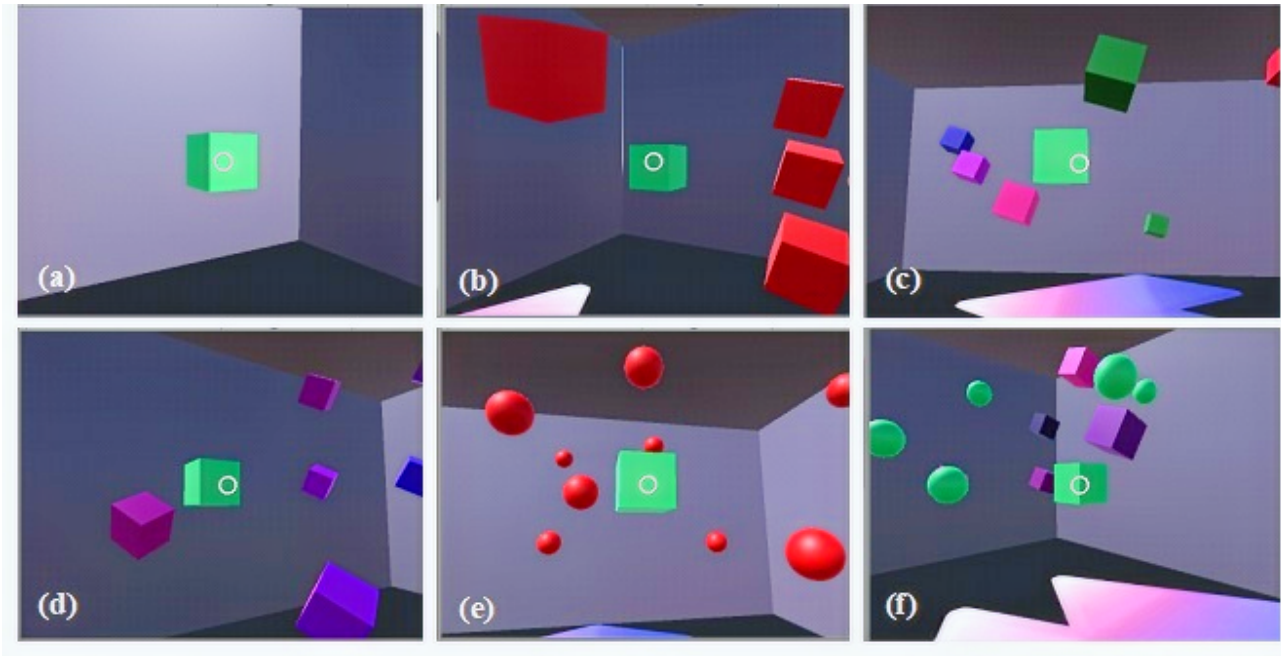
Fig. 3. Example displays for (a) Condition1, (b) Condition2, (c) Condition3, (d) Condition4, (e) Condition5, and (f) Condition6.
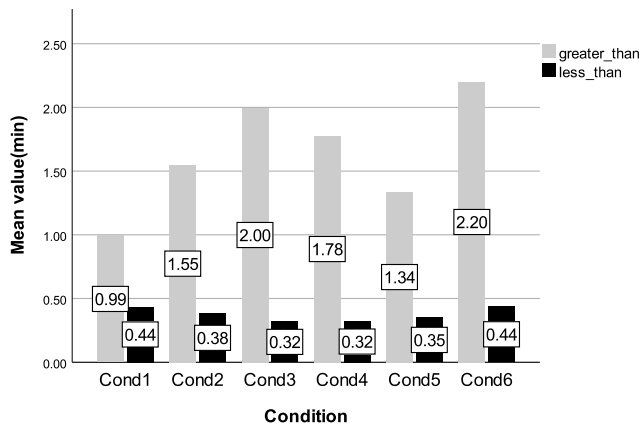


Fig. 4. Condition's mean values less_than and greater_than.



Fig. 5. Time difference per condition.

that the participant reported time less than the actual time, while *greater_than* indicated the opposite. Then we calculated *less_than* as the negative value in the time difference and *greater_than* as the positive value. We used the absolute value for all of the time differences, *less_than*, and *greater_than* values. For each condition, we ran paired samples t-Test between the *less_than* and *greater_than* values to determine the significant condition. The results showed there was a significant difference between *less_than* and *greater_than*, but with a high mean for *greater_than* values (see Fig. 4).

We ran the time difference values through one-way repeated measures ANOVA. Mauchly's test indicated that the assumption of sphericity had not been violated, but when it was violated, the Greenhouse-Geisser corrected tests were reported, $\chi^2(14) = 19.06, p = 0.165$. The results showed that there was a significant main effect of the different visual param-

eters (color, shape, and animation) on the time difference, $F(5, 125) = 2.51, p = 0.034$. Fisher's Least Significant Difference (LSD) post hoc analysis of the results showed that participants significantly overestimated the time duration of cubes-spheres condition ($mean = 1.39; SD = 1.53$) compared to the single-cube condition ($mean = 0.78; SD = 0.80; p = 0.018$) and the spheres condition ($mean = 0.93; SD = 0.99; p = 0.020$). There was no significant difference between the other pairs of conditions. Fig. 5 shows the mean values by condition for the time difference.

We ran the study's search time results values through one-way repeated measures ANOVA. Mauchly's test indicated that the assumption of sphericity was met, $\chi^2(14) = 21.72, p = 0.086$. The results showed that there was no significant main effect of the different visual parameters on search time, $F(5, 125) = 0.393, p = 0.853$. Fig. 6 shows the mean values by condition for the search time.
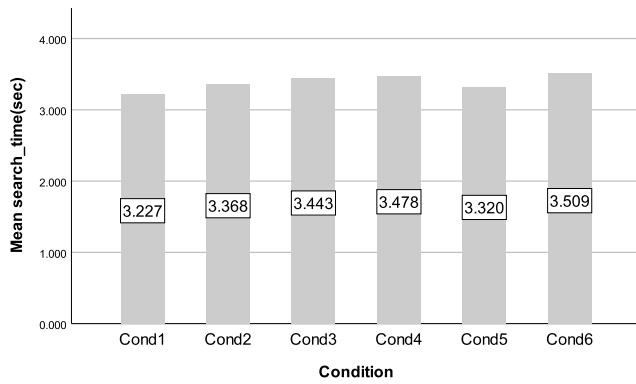
Fig. 6. Search time per condition.



Fig. 7. Mean values for the awareness and illusion errors.

### B. Task Errors

Following in the two sections we are presenting the analysis results for the awareness and illusion errors reported by the participants. Awareness error is the number of missed disruptions, while illusion is the number of disruptions that never happened. These errors were collected to measure the participants' awareness of the surrounding environment.

*1) Awareness error:* For each condition, we ran the awareness error through one-way repeated measures ANOVA. Mauchly's test indicated that the assumption of sphericity was met, $\chi^2(14) = 15.19, p = 0.368$. The results showed that there was a significant main effect of the different visual parameters on the awareness error, $F(5, 125) = 1.29, p = 0.273$. LSD post hoc analysis of the results showed that participants were significantly less aware of their surroundings in the cubes-spheres condition ($mean = 1.38; SD = 1.28$) compared to the single-cube condition ($mean = 0.81; SD = 0.89, p = 0.037$).

*2) Illusion error:* For each condition, we ran the illusion error through one-way repeated measures ANOVA. Mauchly's test indicated that the assumption of sphericity was met, $\chi^2(14) = 16.57, p = 0.282$. The results showed that there was a significant main effect of the different visual parameters on the illusion error, $F(5, 125) = 1.77, p = 0.124$. LSD post hoc analysis of the results showed that participants were significantly less aware of their surroundings in the cubes-spheres condition ($mean = 0.88; SD = 1.14$) compared to the single-cube condition ($mean = 0.38; SD = 0.63, p = 0.030$) and the one-color cubes condition ($mean = 0.31; SD = 0.54, p = 0.041$). Fig. 7 represents the mean values of awareness and illusion errors by condition.

### C. Search Time and Awareness of Surroundings

We ran Spearman's correlation test to determine if there is a relationship between participants' search time and the awareness error. The results showed that search time and awareness error have a statistically significant relationship ($r_s = 0.886, p = 0.019$). The direction of the relationship is positive where search time and error rate are positively correlated, meaning that these variables tend to increase together. The magnitude of the association is strong ($0.5 < |r| < 1.0$).
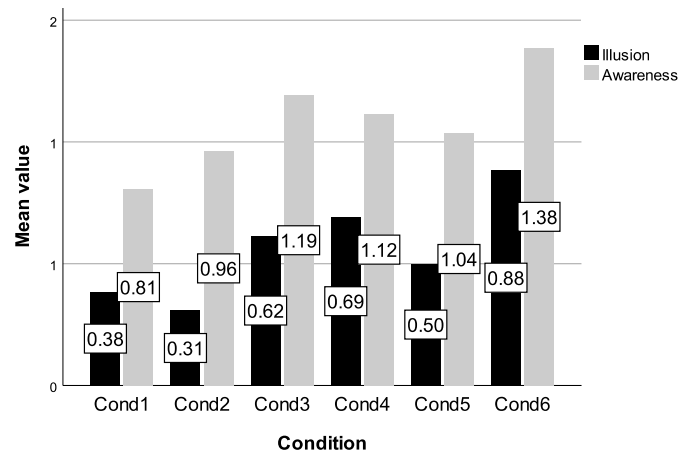
A Spearman's correlation test again was computed to assess the relationship between participants' search time and illusion error. There was a positive correlation between the two variables ($r_s = 0.829, p = 0.042$). Overall, there was a strong, positive correlation between search time and illusion error. Increases in search time were correlated with increases in the rating of illusion error.

### V. Discussion

The goal of this experiment was to determine the impact of different visual parameters on the users' awareness of their surroundings. The least awareness of the surroundings means that the user is highly engaged in the VR content. High engagement increases the levels of immersive experience, thus, increasing the impact of future VR interventions for medical pain distraction.

### A. Completion Time

Based on the study analysis, the time difference (estimated - actual) data revealed that there is a significant difference between the cubes-spheres condition and both the single-cube and the spheres conditions. These results indicated that more attentional resources were engaged in the cube-spheres condition and hence the passage of time got distorted. This implies that the cubes-spheres condition affected the users' perception of time in VR. Due to the visual representation of the target and distractors in the cubes-spheres condition, participants focused their attention on detecting the target and hence failed to judge the time duration.

We further measured the search time of each condition. The analysis showed that there was no significant difference between the six conditions. However, the cubes-spheres condition required more search time to detect the target compared to the remaining conditions. Results revealed that the search time increases when it is hard to identify the target among distractor objects. This implies that the visual representations of the target and distractors affect the search time in VR. Our results revealed that the spheres condition was the lower-order condition against the cubes-spheres condition with the higher-order. The target in the spheres condition had unique

features color and shape, so participants were able to detect it easily. The cubes-spheres condition is the highest due to sharing multiple features color and shape with the distracting objects. Sharing similar features between target and distractors increased the response time for the search task. Our finding comes in line with the conducted research in other 2D and 3D platforms [40], [18]. Fig. 6 shows the mean values of search time for the six conditions.

Another important issue is that the similarity between the (target-distractors) and (distractors-distractors) also affected the search time. In the spheres condition the similarity between the target and distractors was low accompanied by the high similarity between distractors-distractors and in turn, search time decreased. On contrary the target-distractors similarity in the cubes-spheres condition was high and the distractors-distractors similarity was low. Thus, participants in the cubes-spheres condition required more time and also more focused attention to identifying the target. This finding is aligned with the finding presented in [19]. Overall, our findings indicated that the search time was higher when the target and distractors shared similar features. Further, the conjunction of low similarity between distractors-distractors and high similarity between target-distractors provided a long search time. This finding shows a similarity in results between the task search time in VR and desktop 2D platforms.

Finally, it may be worth considering the qualitative data. It is interesting to state that the comments from the participants further supported the statistical findings. For the overestimation of time, participants claimed that the task completion time influenced their judgment of the estimated time. Therefore, as the task became longer the total time was assumed to become longer. This explains why participants overestimated the time duration of the conditions.

### B. Task Errors

The analysis of awareness error showed that there was a significant difference between the cubes-spheres condition and the single-cube condition. As shown in Fig. 7, the cubes-spheres condition has the highest awareness error rate. We found that participants in this condition required more of their focused attention to identifying the target among distractors. Therefore, participants were less aware of their surroundings in this condition compared to the others. Participants missed observation of many auditory and vibration distractions in this condition. As indicated, the cubes-spheres condition included conjunctions of many visual factors that led to increased engagement. Sharing similar features between the target and distractors demanded more attentional resources and hence decreased the participants' awareness of their surroundings. Moreover, participants were less aware of their surroundings when the similarity between target-distractors was high and the similarity between distractors-distractors was low. In line with the previous analysis, the condition that provides more distraction from surroundings is that of the longest search time and the highest awareness error.

Regarding the illusion error, the results showed that participants in the cubes-spheres condition were less aware of their surroundings compared to the single-cube condition and the one-color cube condition. Participants in the cubes-spheres condition reported a significant number of disruptions that never happened, which implies that their focus attention was affected by the visual representations of this condition. Similar to awareness error, participants' attention was significantly engaged in the cubes-spheres condition. The superiority of that condition as an influence on awareness and illusion errors strongly suggests that this condition effectively decreased the participants' awareness of their surroundings. Participants in the cubes-spheres condition consumed a high capacity of attentional resources to detect the target compared to other conditions. This implies that the participants were highly engaged in that condition. In our VR game, the least awareness of the surroundings was provided when the target shared similar features with distractors along with the conjunction of low similarity between distractors-distractors and high similarity between target-distractors. Thus, these visual representations of the target and distraction objects should be considered when developing a VR intervention for pain distraction.

### C. Search Time and Awareness of Surroundings

Regarding the results of search time and task errors (awareness and illusion), there was a strong positive correlation between search time and awareness of the surroundings in immersive VR. When the search task requires more time, the awareness of the surroundings decreases. The awareness of the surroundings is represented by the awareness error and illusion error. Notably, participants lost awareness of their surroundings when the search task required more of their focused attention. Therefore, they missed the observation of many disruptions that were generated during playing the game. The logic behind this is that humans' attentional resources are limited. When the search task requires more time, a great amount of these resources will be captured to perform the task. Thus, less attention is available to process incoming signals from the surroundings. This finding offers potential, especially for medical applications that can make benefit from using VR interventions for pain distraction. Future VR interventions should employ these findings to maximize distraction effects and provide more reduction in pain intensity.

We would like to highlight the following limitations, which should be thoughtfully considered within the context of the study's findings. Firstly, our participant pool was comprised of individuals aged 18 to 24 years, who had minimal experience of using VR. To enhance the generalizability of our findings, future research should encompass more diverse participant populations, spanning various age groups and educational backgrounds. Furthermore, future studies should examine gender and age differences, the outcomes may be linked to variables such as gender and age. Another limitation is related to the relatively short duration of each condition which led to participant overestimation of the time duration. To address this limitation, future studies should consider implementing longer VR interventions. Lastly, this study was limited to examining the main components of visualization however, later we need to examine the combination of these components.

### VI. CONCLUSION

There is solid evidence from controlled research that VR distraction is effective for pain distraction. Based on our knowledge, none of the previous controlled studies has

examined the impact of the different visual parameters on users' awareness of their surroundings in VR, so our study examined in-depth the visual parameters and their impact on users' awareness of their surroundings. Results showed that when the search task required more time, the awareness and illusion errors were high. High errors indicate less awareness of the surroundings and more engagement in the game. Moreover, results revealed visual features that affect search time and capture a viewer's focus of attention in 2D games are also feasible in VR. This key finding in addition to immersion renders VR an effective tool for pain distraction. This study is an elementary study conducted to determine the visual representation of target and distractors that provides the least awareness of the surroundings in VR. This visual representation will be employed in our next VR game designed for distracting patients from pain. By using VR technology we may make a significant step towards increasing the therapeutic benefits of VR for pain management.

## REFERENCES

[1] E. Goodman-Vincent, M. Roy, and N. Khalili-Mahani, "Affective game planning for playing the pain: An experimental framework for testing the analgesic efficacy of market-place mobile games," in *Extended Abstracts of the 2020 Annual Symposium on Computer-Human Interaction in Play*, 2020, pp. 122–128.

[2] M. V. Birk and R. L. Mandryk, "Improving the efficacy of cognitive training for digital mental health interventions through avatar customization: crowdsourced quasi-experimental study," *Journal of medical Internet research*, vol. 21, no. 1, p. e10133, 2019.

[3] K. A. Wohlheiter and L. M. Dahlquist, "Interactive versus passive distraction for acute pain management in young children: The role of selective attention and development," *Journal of pediatric psychology*, vol. 38, no. 2, pp. 202–212, 2013.

[4] K. D. McCaul and J. M. Malott, "Distraction and coping with pain." *Psychological bulletin*, vol. 95, no. 3, p. 516, 1984.

[5] M. D. Griffiths, "The therapeutic and health benefits of playing video games," in *The Oxford handbook of cyberpsychology*, 2019.

[6] L. San Roque, K. H. Kendrick, E. Norcliffe, P. Brown, R. Defina, M. Dingemanse, T. Dirksmeyer, N. J. Enfield, S. Floyd, J. Hammond *et al.*, "Vision verbs dominate in conversation across cultures, but the ranking of non-visual verbs varies," *Cognitive Linguistics*, vol. 26, no. 1, pp. 31–60, 2015.

[7] E. Chayadi and B. L. McConnell, "Gaining insights on the influence of attention, anxiety, and anticipation on pain perception," *Journal of Pain Research*, vol. 12, p. 851, 2019.

[8] C. Bascour-Sandoval, S. Salgado-Salgado, E. Gómez-Milán, J. Fernández-Gómez, G. A. Michael, and G. Gálvez-García, "Pain and distraction according to sensory modalities: Current findings and future directions," *Pain Practice*, vol. 19, no. 7, pp. 686–702, 2019.

[9] R. J. Hirst, L. Cragg, and H. A. Allen, "Vision dominates audition in adults but not children: A meta-analysis of the colavita effect," *Neuroscience & Biobehavioral Reviews*, vol. 94, pp. 286–301, 2018.

[10] M. L. Heilig, "El cine del futuro: The cinema of the future." *Presence Teleoperators Virtual Environ.*, vol. 1, no. 3, pp. 279–294, 1992.

[11] D. Kim and Y. J. Ko, "The impact of virtual reality (vr) technology on sport spectators' flow experience and satisfaction," *Computers in human behavior*, vol. 93, pp. 346–356, 2019.

[12] A. S. Hundert, K. A. Birnie, O. Abla, K. Positano, C. Cassiani, S. Lloyd, P. H. Tiessen, C. Lalloo, L. A. Jibb, and J. Stinson, "A pilot randomized controlled trial of virtual reality distraction to reduce procedural pain during subcutaneous port access in children and adolescents with cancer," *The Clinical journal of pain*, vol. 38, no. 3, pp. 189–196, 2022.

[13] B. Mallari, E. K. Spaeth, H. Goh, and B. S. Boyd, "Virtual reality as an analgesic for acute and chronic pain in adults: a systematic review and meta-analysis," *Journal of pain research*, vol. 12, p. 2053, 2019.

[14] C.-C. Chang, C. Liang, P.-N. Chou, and G.-Y. Lin, "Is game-based learning better in flow experience and various types of cognitive load than non-game-based learning? perspective from multimedia and media richness," *Computers in Human Behavior*, vol. 71, pp. 218–227, 2017.

[15] A. I. Nordin, P. A. Cairns, M. Hudson, A. Alonso, and E. H. C. Gámez, "The effect of surroundings on gaming experience." in *FDG*, 2014.

[16] F. E. Ibrahim, N. A. M. Elsayed, and H. H. Zayed, "A survey on the effectiveness of virtual reality-based therapy and pain management," *International Journal of Advanced Computer Science and Applications*, vol. 12, no. 7, 2021.

[17] J. M. Wolfe, "Visual search: How do we find what we are looking for?" *Annual Review of Vision Science*, vol. 6, pp. 539–562, 2020.

[18] A. M. Treisman and G. Gelade, "A feature-integration theory of attention," *Cognitive psychology*, vol. 12, no. 1, pp. 97–136, 1980.

[19] J. Duncan and G. W. Humphreys, "Visual search and stimulus similarity." *Psychological review*, vol. 96, no. 3, p. 433, 1989.

[20] J. Steuer, "Defining virtual reality: Dimensions determining telepresence," *Journal of communication*, vol. 42, no. 4, pp. 73–93, 1992.

[21] M. El Beheiry, S. Doutreligne, C. Caporal, C. Ostertag, M. Dahan, and J.-B. Masson, "Virtual reality: beyond visualization," *Journal of molecular biology*, vol. 431, no. 7, pp. 1315–1321, 2019.

[22] M. Guenther, D. Görlich, F. Bernhardt, E. Pogatzki-Zahn, B. Dasch, J. Krueger, and P. Lenz, "Virtual reality reduces pain in palliative care–a feasibility trial," *BMC Palliative Care*, vol. 21, no. 1, pp. 1–9, 2022.

[23] B. G. Witmer and M. J. Singer, "Measuring presence in virtual environments: A presence questionnaire," *Presence*, vol. 7, no. 3, pp. 225–240, 1998.

[24] L. Jarvis, "Narrative as virtual reality 2: revisiting immersion and interactivity in literature and electronic media: by marie-laure ryan, baltimore, john hopkins university press, 2015, 304 pp., isbn 9781421417974," 2019.

[25] C. Anthes, R. J. García-Hernández, M. Wiedemann, and D. Kranzlmüller, "State of the art of virtual reality technology," in *2016 IEEE Aerospace Conference*. IEEE, 2016, pp. 1–19.

[26] M. Pittara, M. Matsangidou, K. Stylianides, N. Petkov, and C. S. Pattichis, "Virtual reality for pain management in cancer: A comprehensive review," *IEEE Access*, vol. 8, pp. 225 475–225 489, 2020.

[27] N. A. Baker, A. H. Polhemus, E. H. Ospina, H. Feller, M. Zenni, M. Deacon, G. DeGrado, S. Basnet, and M. Driscoll, "The state of science in the use of virtual reality in the treatment of acute and chronic pain: A systematic scoping review," *The Clinical Journal of Pain*, vol. 38, no. 6, pp. 424–441, 2022.

[28] H. G. Hoffman, R. A. Rodriguez, M. Gonzalez, M. Bernardy, R. Peña, W. Beck, D. R. Patterson, and W. J. Meyer III, "Immersive virtual reality as an adjunctive non-opioid analgesic for pre-dominantly latin american children with large severe burn wounds during burn wound cleaning in the intensive care unit: a pilot study," *Frontiers in human neuroscience*, vol. 13, p. 262, 2019.

[29] R. R. Ali, A. O. Selim, M. A. A. Ghafar, O. R. Abdelraouf, and O. I. Ali, "Virtual reality as a pain distractor during physical rehabilitation in pediatric burns," *Burns*, vol. 48, no. 2, pp. 303–308, 2022.

[30] S. Scapin, M. E. Echevarría-Guanilo, P. R. B. F. Junior, N. Goncalves, P. K. Rocha, and R. Coimbra, "Virtual reality in the treatment of burn patients: A systematic review," *Burns*, vol. 44, no. 6, pp. 1403–1416, 2018.

[31] T. Jones, T. Moore, and J. Choo, "The impact of virtual reality on chronic pain," *PloS one*, vol. 11, no. 12, p. e0167523, 2016.

[32] B. M. Garrett, G. Tao, T. Taverner, E. Cordingley, and C. Sun, "Patients perceptions of virtual reality therapy in the management of chronic cancer pain," *Heliyon*, vol. 6, no. 5, p. e03916, 2020.

[33] S. M. Schneider, C. K. Kisby, and E. P. Flint, "Effect of virtual reality on time perception in patients receiving chemotherapy," *Supportive Care in Cancer*, vol. 19, no. 4, pp. 555–564, 2011.

[34] H. G. Hoffman, D. R. Patterson, G. J. Carrougher, D. Nakamura, M. Moore, A. Garcia-Palacios, and T. A. Furness Iii, "The effectiveness of virtual reality pain control with multiple treatments of longer durations: A case study," *International Journal of Human-Computer Interaction*, vol. 13, no. 1, pp. 1–12, 2001.

[35] A. W. Faber, D. R. Patterson, and M. Bremer, "Repeated use of immersive virtual reality therapy to control pain during wound dressing changes in pediatric and adult burn patients," *Journal of Burn Care & Research*, vol. 34, no. 5, pp. 563–568, 2013.

[36] T. Jones, R. Skadberg, and T. Moore, "A pilot study of the impact of repeated sessions of virtual reality on chronic neuropathic pain." *International Journal of Virtual Reality*, vol. 18, no. 1, 2018.

[37] H. G. Hoffman, W. J. Meyer III, M. Ramirez, L. Roberts, E. J. Seibel, B. Atzori, S. R. Sharar, and D. R. Patterson, "Feasibility of articulated arm mounted oculus rift virtual reality goggles for adjunctive pain control during occupational therapy in pediatric burn patients,"

*Cyberpsychology, Behavior, and Social Networking*, vol. 17, no. 6, pp. 397–401, 2014.

[38] C. G. Ford, E. M. Manegold, C. L. Randall, A. M. Aballay, and C. L. Duncan, "Assessing the feasibility of implementing low-cost virtual reality therapy during routine burn care," *Burns*, vol. 44, no. 4, pp. 886–895, 2018.

[39] C. Khadra, A. Ballard, D. Paquin, C. Cotes-Turpin, H. G. Hoffman, I. Perreault, J.-S. Fortin, S. Bouchard, J. Théroux, and S. Le May, "Effects of a projector-based hybrid virtual reality on pain in young children with burn injuries during hydrotherapy sessions: A within-subject randomized crossover trial," *Burns*, vol. 46, no. 7, pp. 1571–1584, 2020.

[40] B. Olk, A. Dinu, D. J. Zielinski, and R. Kopper, "Measuring visual search and distraction in immersive virtual reality," *Royal Society open science*, vol. 5, no. 5, p. 172331, 2018.

# A Comparative Study of Deep Learning Algorithms for Forecasting Indian Stock Market Trends

Mrinal Kanti Paul, Purnendu Das

Department of Computer Science, Assam University, Silchar, Assam, India-788011

*Abstract*—This research underscores the vital significance of providing investors with timely and dependable information within the dynamic landscape of today's stock market. It delves into the expanding utilization of data science and machine learning methods for anticipating stock market movements. The study conducts a comprehensive analysis of past research to pinpoint effective predictive models, with a specific focus on widely acknowledged algorithms. By employing an extensive dataset spanning 27 years of NIFTY 50 index data from the National Stock Exchange (NSE), the research facilitates a thorough comparative investigation. The primary goal is to support both investors and researchers in navigating the intricate domain of stock market prediction. Stock price prediction is challenging due to numerous influencing factors, and identifying the optimal deep learning model and parameters is a complex task. This objective is accomplished by harnessing the capabilities of deep learning, thereby contributing to well-informed decision-making and the efficient utilization of predictive tools. The paper scrupulously examines prior contributions from fellow researchers in stock prediction and implements established deep learning algorithms on the NIFTY 50 dataset to assess their predictive accuracy. The study extensively analyzes NIFTY 50 data to anticipate market trends. It employs three distinct deep learning models—RNN, SLSTM, and BiLSTM. The results underscore SLSTM as the most effective model for predicting the NIFTY 50 index, achieving an impressive accuracy of 99.10%. It's worth noting that the accuracy of BiLSTM falls short when compared to RNN and SLSTM.

*Keyword*—*Stock prediction; machine learning technique; deep learning; stock market; National Stock Exchange*

## I. Introduction

Scholars have been actively engaged in researching the prediction of stock trends due to the stock market's pivotal role as a significant investment avenue across various financial instruments. The goal of stock portfolio selection is to allocate investment funds across multiple stocks in the market, aiming to maximize returns for investors [1]. Investors encounter two broad categories of challenges when creating stock portfolios "The selection of stocks by an investor" and "Allocating funds across various major sectors"

With the advent of faster and high-performance computers, data transfer in the modern computing world has become effortless, making the stock market more accessible to global investors. The internet revolution of the last decade further increased accessibility, as it provides crucial event information that directly or indirectly influences the stock market, leading to the emergence of important tasks like strategy formulation and decision-making support using this information.

Data science (DS) and machine learning (ML) algorithms have become powerful tools in the financial domain, sig-

nificantly improving stock investments' efficiency. They are extensively utilized to develop innovative ideas and modes that simplify the process of creating stock portfolios for investors [2].

This paper delves into the growing interest among financial researchers in Machine Learning (ML) owing to its success in various domains. It focuses on exploring and comparing the latest prediction algorithms and techniques proposed by researchers for forecasting stock market trends and behavior in both academic and industry settings.

This paper encompasses a concise overview of both Machine Learning (ML) and Deep Learning algorithms. It goes on to conduct a thorough examination of a wide array of algorithms, coupled with an extensive survey of correlated research. This inclusive approach serves to fortify the theoretical underpinnings of the study while also delving into pertinent algorithmic issues. Moreover, the research delves into the practical application of existing work and prevalent deep learning algorithms, commonly employed as the bedrock of numerous researchers' investigations. A pivotal aspect of this study involves a comprehensive comparative analysis of the outcomes achieved through these algorithms.

To accomplish our research objectives, we conducted an extensive survey of prior studies on stock market prediction utilizing data science and machine learning. We meticulously analyzed the methodologies and algorithms employed by various researchers to forecast stock prices. Moreover, we assembled an extensive dataset of NIFTY 50 data obtained from the National Stock Exchange India, covering a period of 27 years. This dataset facilitated a comprehensive evaluation of prediction models across a range of market scenarios.

This study involves a comparative analysis of well-known algorithms: LSTM, BiLSTM, SVM, and RNN. The analysis utilizes a collected dataset as training data to predict NIFTY 50 stock index movement accurately. The primary goal is to identify the algorithm that performs best in terms of predictive accuracy. The algorithms are trained on the dataset, and their performances are evaluated using appropriate metrics. The study aims to offer insights into which algorithm is most effective for predicting NIFTY 50 movement, aiding in more informed decision-making within the financial realm. The study focuses on four algorithms: SLSTM (Stacked Long Short-Term Memory), BiLSTM (Bidirectional Long Short-Term Memory) and RNN (Recurrent Neural Network). Fig. 1 depicts the process flow of our study.

In the upcoming sections of this paper, we will delve into various aspects of our study. Section II will be dedicated to discussing the related work that has shaped the foundation of

our research. Moving forward to Section III, we will provide an in-depth description of our implementation plan. Within Section III , specifically in subsection III(A) and III(A)(1), we detail our meticulous implementation process using the RNN model. Furthermore, we will present a comprehensive analysis of the results derived from this implementation. Transitioning to subsection III(B) and III(B)(1), we will outline the steps taken for the implementation of the SLSTM model. Alongside this, we will conduct a thorough examination of the results obtained from this implementation. Similarly, in subsection III(C) and III(C)(1), we will provide insights into our implementation approach for the BiLSTM model and present a comprehensive analysis of the results.

Advancing to Section IV, our focus will shift towards conducting a Comparative Study of the results derived from our various implementations. This section will not only provide a comprehensive comparison of the implementation outcomes but will also identify potential avenues for Future Research Opportunities, illuminating areas that warrant further exploration. As we reach the concluding stages of this paper, Section V will encapsulate our findings and insights. This concluding section will succinctly summarize the key takeaways from our research journey, offering a cohesive wrap-up to our study.

## II. Related Works

In the history of the stock market, researchers have employed algorithms like Neural Networks (NN), Support Vector Machines (SVM), Genetic Algorithms (GA), Linear Regression (LR) and Case based Reasoning (CR) for predicting market trends. However, Neural Networks (NN) have gained prominence recently due to their consistent superiority in various scenarios. Their ability to capture intricate patterns in financial data has led to more accurate and adaptable predictions of market behavior, making them the preferred choice among these algorithms [3].

White's implementation of the Feed Forward Neural Network (FFNN) was the pioneering stock market prediction model, inspiring many researchers to develop accurate models for predicting share market trends. Despite continuous efforts, achieving 100% accuracy in stock market forecasting remains elusive due to historical data reliance and external factors' impact on stock prices, driving persistent research in this domain [3].

Earlier research emphasized optimizing learning algorithms but overlooked dimensionality reduction and eliminating irrelevant patterns. To overcome this, Kyoung-jae Kim and Ingoo Han introduced a hybrid model in the early 2000s, blending Artificial Neural Networks (ANN) and Genetic Algorithm (GA). Their model incorporated daily direction of change and technical indicators for Korea Stock Price Index prediction, yet it had limitations in fixed processing elements, input features and optimization objectives in the hidden layer (set at 12) [4].

Mingyue Qiu et al a hybrid solution, GA-ANN, aimed at forecasting the Japanese Stock Market. Their method involved integrating Genetic Algorithms (GA) with a refined Artificial Neural Network (ANN) model, resulting in an enhanced predictive model. This approach combined the strengths of both techniques to achieve improved forecasting outcomes for the Japanese Stock Market [5].

M.R. Hassan and B. Nath proposed the use of Hidden Markov Model (HMM) for predicting unknown values in time-series stock market data. They applied this model to forecast stock prices for four airlines, utilizing a partitioned approach that involved four distinct states for more accurate predictions [6]. The paper's noteworthy aspect is that it doesn't require any specialized knowledge to construct the model. However, the study's limitations are that it's restricted to Airline Industries and was evaluated using a relatively small-scale dataset, which might not result in a general prediction model.

Ming-Chi Lee's paper introduced a Support Vector Machine based prediction model with a hybrid feature selection approach that combined Supported Sequential Forward Search (FSSFS) and F-score filtering wrapping methods. This fusion aimed to identify an optimal feature subset for improved prediction. The study acknowledges feature selection's impact on SVM performance and highlights the need for further investigation into SVM generalization and performance measurement guidelines [7].

Justin Sirignano and Rama Cont introduced a model utilizing Deep Learning on a large-scale, high-frequency dataset from NASDAQ stocks. Their approach involves a Neural Network with three layers, including LSTM, a feed-forward layer with rectified linear units (ReLUs) and the Stochastic Gradient Descent (SGD) algorithm for optimization [8]. The model developed by the authors was regarded as a universal solution but incurred high training costs. They observed that conducting feature selection before training would have been more beneficial, effectively lowering computational complexity.

Li-Ping Ni et al. suggested a predictive model for the Shanghai Stock Exchange Index (SSECI) daily trends. They combined a fractal feature selection method with SVM and compared it against five common feature selection approaches, demonstrating superior prediction accuracy with their method and surpassing both no feature selection and the other five methods [9]. The authors' model, based solely on a technical indicator, should be assessed with additional factors that influence stock prices, given the multifaceted nature of stock price dynamics.

Sean McNally et al. devised a model predicting Bitcoin's USD price using Bayesian-optimized LSTM and RNN networks. LSTM achieved 52% accuracy and 8% RMSE. Comparing to ARIMA, their deep learning models excelled. GPU training surpassed CPU by 67.7%, underscoring research strength in optimization and feature engineering, with implications for dataset processing advancements [10].

Bin Wenga et al. Martinez created a short-term stock price prediction model employing machine learning techniques including Random Forest Regression (RFR), Support Vector Regression Ensemble (SVRE), Neural Network Regression Ensemble (NNRE) and Boosted Regression Trees (BRT) [11].

Yakup Kara et al. utilized ANN and SVM to predict the stock price index, using time series data from Istanbul Stock Exchange between January 1997 and December 2007. Their study lacked clear performance comparisons with prior models. They employed diverse data sets from various sources, including open-source APIs and the Technical Training Rules (TTR) R package, for training their research model [12].

Xinyi Li and colleagues introduced DP-LSTM, an innovative deep neural network for predicting stock prices. By integrating differential privacy, sentiment-ARMA modeling, LSTM, VADER model, and multiple news sources, the approach minimizes prediction errors, enhances robustness, and demonstrates significant advancements in accuracy and Mean Squared Error (MSE) improvement for forecasting the S&P 500 market index [13].

Sidra Mehtab et al. conducted a study using NIFTY 50 index data from India's NSE, covering December 2014 to July 2020. They initially trained on NIFTY 50 data from December 2014 to December 2018, developing eight regression models. Subsequently, they forecasted NIFTY 50 open values from December 2018 to July 2020, employing four LSTM-based deep learning regression models with walk-forward validation. Their research highlighted the efficacy of a univariate LSTM model in predicting NIFTY 50 open values for the following week, utilizing the preceding week's data as input, leading to enhanced predictive accuracy [14].

Hadi NekoeiQachkanloo et al. introduced an artificial stock counselor trading system, combining support vector regression for stock value prediction with portfolio theory and fuzzy investment counsel for optimal budget allocation. Their approach encompasses optimization-based technical analysis and fuzzy logic incorporating technical and fundamental aspects, demonstrating efficacy through experimental results on the NYSE [15].

In their study, M. Nabipour et al. explored the accuracy of tree-based models (Decision Tree, Bagging, Random Forest, Adaboost, Gradient Boosting, XGBoost) and neural networks (ANN, RNN, LSTM) in predicting values for four stock market sectors using regression. Forecasting was done across different time horizons (1, 2, 5, 10, 15, 20, and 30 days ahead), employing exponentially smoothed technical indicators as inputs. The research found that LSTM outperformed other methods, showcasing the highest performance and notably improving the accuracy of stock market predictions within this context [16].

Hiransha M et al. employed MLP, RNN, LSTM, and CNN deep learning architectures to predict stock prices across NSE and NYSE. Using TATA MOTORS' NSE data, these models accurately forecasted prices for MARUTI, HCL, AXIS BANK (NSE), as well as BANK OF AMERICA and CHESAPEAKE ENERGY (NYSE). The study demonstrated the models' ability to identify patterns in both markets, revealing shared dynamics. DL models outperformed ARIMA and CNN excelled in capturing sudden changes, although the research did not explore hybrid network approaches for further improvement [17].

Manuel R. Vargas et al. proposed a deep learning approach combining financial news titles and technical indicators for predicting intraday directional movements of the S&P 500 index. Their study emphasized Convolutional Neural Networks (CNN) for extracting text meaning and Recurrent Neural Networks (RNN) for capturing context and temporal trends, achieving improved results over similar prior work. Notably, the model's utilization of news from the preceding day underscored the short-term impact of news articles on financial market predictions [18].

Qingfu Liu et al. innovatively treat stock price charts as images and utilize deep learning neural networks (DLNNs) to predict short-term price movements by integrating price charts and stock fundamentals. The study highlights the supremacy of deep learning over single-layer models in forecasting the Chinese stock market, underlining the importance of historical price trends in predicting future price changes compared to stock fundamentals [19].

Somenath Mukherjee et al. introduced a pair of approaches for predicting stock market trends. The first utilized a Feed-forward Neural Network with backpropagation, achieving 97.66% prediction accuracy but facing challenges with data volume and overfitting. Regularization was applied to address these issues. The second approach employed a Convolutional Neural Network, offering a more efficient solution with improved accuracy (98.92%) on a smaller dataset and training time, outperforming the initial model [20].

Yanli Zhao et al. proposed an innovative LSTM-based model enriched with sentiment analysis to predict stock market trends, acknowledging the impact of investor psychology. The study integrated sentiment indexes to capture emotional facets, utilizing Sentiment Analysis (SA) to convert textual content into daily sentiment indexes. The model's refinement with Denoising Autoencoders (DAE) improved its performance by extracting crucial information [21].

Abdul Quadir Md and collaborators present an innovative strategy for stock price prediction that employs a Multi-Layer Sequential Long Short Term Memory (MLS LSTM) model integrated with the Adam optimizer. This technique involves dividing normalized time series data into discrete time steps, effectively capturing historical and future associations and yielding remarkable prediction accuracy rates of 95.9% and 98.1% on the test dataset, outperforming alternative deep learning approaches. [22].

Arsalan Dezhkam et al. introduced HHT-XGB, a novel model that merges Hilbert-Huang Transform (HHT) for feature engineering and extreme gradient boost (XGBoost) for close price trend classification, facilitating the prediction of changing trends in upcoming close stock prices. The model's output sequence optimizing portfolio weights demonstrated a remarkable 99.8% improvement over raw financial data, surpassing benchmark strategies even in challenging market conditions, substantiated through back-testing results [23].

Liheng Zhang et al. introduced the State Frequency Memory recurrent network, designed to capture diverse trading patterns and enhance short and long-term stock predictions. Their novel approach demonstrates superior performance compared to conventional methods in real market data analyses [24].

Guanzhi Li et al. presented a novel framework consisting of Pearson Correlation Coefficient (PCC) and Bayesian Regularized Neural Network Least Squares (BLS), applied for short-term stock price prediction in Shenzhen and Shanghai Stock Exchanges. The approach involved using PCC to select relevant input variables from a pool of 35 variables, followed by training the BLS model with these chosen combinations. The PCC-BLS model demonstrated superior accuracy compared to ten other machine learning methods, as evidenced by results across five evaluation metrics [25].

Shouvik Banik et al. created an LSTM-based Decision Support System for accurate stock value prediction, catering to swing traders. The system generates comprehensive reports with forecasts for the next 30 days, incorporating technical indicators like MFI, RSI, Support and Resistance levels, Fibonacci retracement levels, and MACD analysis. The model's strong performance, boasting low error values, underscores its superiority over existing methods [26].

Stock prices are impacted by politics, economics, news, and investors use fundamental and technical analysis for predictions [27]. Fundamental analysis of a company's stock involves evaluating historical performance, anticipated future growth, and key factors such as profits, product quality, industry competition, financial balance, and cash flow projections [28]. Technical analysis involves predicting stock price trends through market trends and statistical data, addressing questions like optimal buying and selling times. It relies on tables, charts, and coefficients to make short-term and long-term predictions for specific stocks [28]. The review of existing studies and comparisons highlights the success of deep learning models like LSTM, ANN, RNN, SVM, SLSTM and BiLSTM in achieving accurate stock price predictions with minimal error. This prompts our exploration into studying these algorithms for potential research opportunities. We did a comparative study of all the machine learning algorithms used till date in financial instruments.

### III. IMPLEMENTATION

#### A. Experimental Setup

In this research paper, our focus lies in implementing and comparing three distinct models: RNN, SLSTM, and BiLSTM. Our primary goal revolves around evaluating and contrasting their performance utilizing data sourced from the National Stock Exchange. Specifically, we're utilizing the NIFTY 50 index dataset, which covers a substantial 27-year timeframe, ranging from January 1, 1997, to December 31, 2021. This dataset comprises an extensive record of over 6000 days, detailing NIFTY 50 movements. The dataset includes data attributes such as Opening, High, Low, and Closing values. However, our primary attention within this study is focused on the Closing value, as our objective centers on forecasting daily index movements.
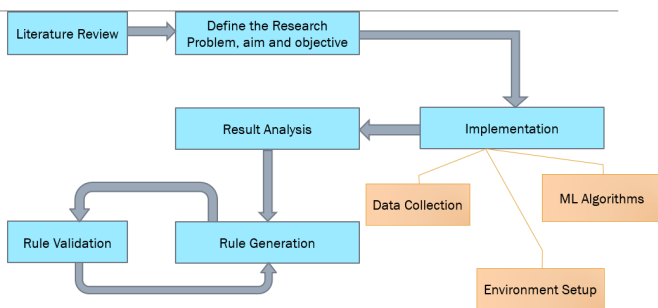


Fig. 1. Process flow diagram.

Throughout our experimental setup, we've meticulously partitioned the dataset into two segments: 70% for training and the remaining 30% for rigorous testing and validation purposes. This meticulous division allows us to methodically appraise the predictive prowess of the RNN, SLSTM, and BiLSTM models when applied to the NIFTY 50 dataset.

It's essential to note that during the data preprocessing phase, we've diligently filtered out records with missing closing values or date fields, as well as those with incorrect data types. This meticulous approach ensures the dataset's uniformity and consistency, providing a solid foundation for our models' assessments. Fig. 2 on page 935 displays the NIFTY 50 closing values from 1997 to 2021.



Fig. 2. NIFTY 50 movement from 1997 to 2021.

The Fig. 3 on page 936 illustrates the sequential process of our experimental framework, which is specifically designed for predicting the closing movements of NIFTY 50. Our approach involves the utilization of the deep learning model mentioned previously. In our experimentation, we systematically evaluated these models across three distinct setups. Our aim was to derive valuable rules from these evaluations and ultimately identify a model and combination of factors that not only yield high predictive accuracy but also enhance efficiency in forecasting NIFTY 50 closing movements.

#### B. Implementation of Recurrent Neural Network on Nifty 50 Index Dataset

RNNs are a Neural Network variant that handles sequences by utilizing the previous step's output as the current step's input. The standout feature is the hidden state, acting as memory, which preserves sequence information. This memory state, also called the Memory State, empowers the network to grasp sequential relationships and patterns in data. While Recurrent Neural Networks (RNNs) share the input-output structure with other deep neural architectures, they diverge in how information flows. Unlike traditional architectures with distinct weight matrices per layer, RNNs maintain consistent weights across the network. They compute hidden states $(H_i)$ for inputs $(X_i)$ using specific formulas, allowing the network to retain memory across sequences.

We employed the RNN algorithm for predicting NIFTY 50 index movements, utilizing a dataset spanning January 1, 1997, to December 31, 2021. Our strategy centered on forecasting closing values based on historical closing points. The structure consisted of four layers of regressors with a dropout rate of 0.2. Moreover, we integrated a dense layer housing a single neuron. Optimization was achieved through the utilization of the Adam optimizer, aiming to elevate the overall performance of the deep learning model. We systematically endeavored to enhance the model's predictive abilities through 12 diverse
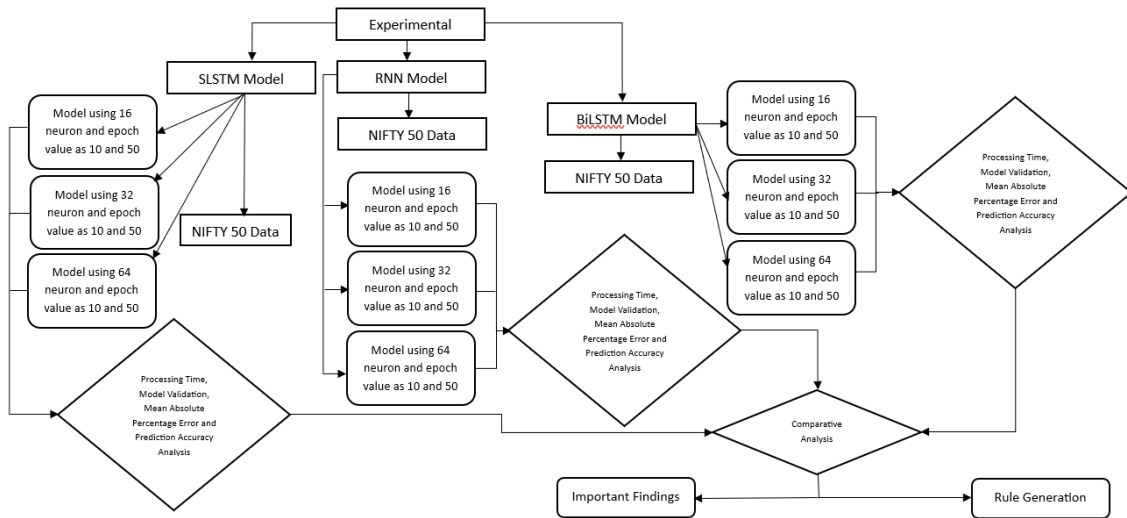
Fig. 3. Overall experimental framework.

TABLE I. RNN PREDICTION RESULTS

| Sr. | Number of Neurons in RNN | Batch Size | Number of Neuron in Dense Layer | Epoch | Sequence Length | Training Time | Mean Absolute Percentage Error | Prediction Accuracy |
|---|---|---|---|---|---|---|---|---|
| 1 | 16 | 10 | 1 | 10 | 15 | 104.81 | 1.97 | 98.03 |
| 2 | 32 | 10 | 1 | 10 | 15 | 122.66 | 2.38 | 97.62 |
| 3 | 64 | 10 | 1 | 10 | 15 | 143.77 | 2.02 | 97.98 |
| 4 | 16 | 10 | 1 | 50 | 15 | 487.67 | 2.33 | 97.66 |
| 5 | 32 | 10 | 1 | 50 | 15 | 588.08 | 1.75 | 98.25 |
| 6 | 64 | 10 | 1 | 50 | 15 | 643.61 | 3.7 | 96.3 |
| 7 | 16 | 32 | 1 | 10 | 15 | 44.19 | 4.06 | 95.94 |
| 8 | 32 | 32 | 1 | 10 | 15 | 49.04 | 1.60 | 98.40 |
| 9 | 64 | 32 | 1 | 10 | 15 | 58.62 | 1.59 | 98.41 |
| 10 | 16 | 32 | 1 | 50 | 15 | 193.112 | 1.77 | 98.23 |
| 11 | 32 | 32 | 1 | 50 | 15 | 218 | 1.81 | 98.19 |
| 12 | 64 | 32 | 1 | 50 | 15 | 242.26 | 1.35 | 98.65 |

combinations of neuron counts, batch sizes, and epochs. Here, epochs refer to the total number of complete passes made through the training dataset. The accompanying Table I on page 936 visually presents the outcomes of our tests, offering insights into the predictive efficacy of the RNN models across various configurations.

*1) Result analysis:* After a comprehensive analysis of the NIFTY 50 closing movement predictions using RNN across 12 distinct configurations (as outlined in Table I on page 936), we have identified a standout performer. Specifically, the RNN model with 64 neurons, a batch size of 32, and 50 training epochs consistently outperformed all other combinations in terms of prediction accuracy. Impressively, this configuration achieved an average prediction accuracy of 98.65%, demonstrating its robust performance. Additionally, the training time for this model was deemed satisfactory.

In Fig. 4(a), we present a visual comparison between the predicted and actual movement of NIFTY 50 closing prices, along with the associated differences. This graphical representation showcases the alignment of the predicted movement with the real data. Furthermore, Fig. 4(c) illustrates the training data's movement and provides a detailed comparison between the predicted and actual movements. The chart in Fig. 4(b) provides insights into the prediction accuracy versus error

analysis, showcasing the model's proficiency in estimating values.

Graphs depicting the loss vs. epoch are a valuable tool for visualizing the training progress of a neural network. This graphical representation involves plotting the loss metric on the vertical axis against the number of training epochs on the horizontal axis. Each point along the line represents the loss value recorded in consecutive epochs. In this context, the Fig. 4(d) illustrates the loss vs. epoch graph for the RNN model that achieved the highest accuracy in predicting the movement. This visual representation allows for a clear understanding of how the model's loss evolves throughout the training process, offering insights into its learning dynamics and convergence.

### C. Implementation of Stacked Long Short-Term Memory on Nifty 50 Index Dataset

LSTM (Long Short-Term Memory) stands out as a highly potent solution for tackling sequence prediction challenges. Its strength lies in its ability to retain past information, a critical factor for predicting future trends and records in daily QC items. Unlike traditional RNNs, LSTM networks effectively mitigate the issues of forgetting and gradient vanishing through the incorporation of self-loops and a unique internal gate structure. LSTM's unique architecture is characterized by four

(a) Prediction vs. actual vs. difference.



(b) Accuracy percentage vs. MAPE.



(c) RNN model implementation data.



(d) Losses vs. epoch.

Fig. 4. RNN model testing matrix (a) Prediction vs. actual vs. difference, (b) Accuracy Percentage vs. MAPE, (c) RNN model implementation data, (d) Losses vs. epoch.

essential gates: Input Gate, Cell State, Forget Gate and Output Gate. The forget gate plays a crucial role in determining which information is allowed to pass through the cell. Subsequently, the input gate decides how much new information should be incorporated into the cell state. Finally, the output gate regulates the information that is used for generating the output message. The development of the LSTM network was motivated by the necessity to address the challenge of vanishing gradients. The critical breakthrough in the design of LSTM involves incorporating non-linear, data-dependent controls into the RNN cell. These controls are trainable elements that serve the purpose of preventing the gradient of the objective function from diminishing in relation to the state signal. This innovation significantly boosts the network's ability to learn during training and enhance its predictive potential [29].

A SLSTM, an extension of the LSTM architecture, involves layering multiple LSTM units to process sequential data. Each layer in the stack handles output sequences from the preceding one, enabling the model to grasp intricate patterns. This layered structure enhances the model's ability to learn hierarchical features and representations in the data, similar to deep neural networks. Stacked LSTMs excel in capturing complex temporal patterns in sequences, making them valuable for tasks like time series prediction, natural language processing, and speech recognition. The accompanying Table II on page 938 visually presents the outcomes of our tests, offering insights into the predictive efficacy of the SLSTM models across various configurations.

*1) Result analysis:* Upon conducting a comprehensive analysis of NIFTY 50 closing movement predictions using SLSTM across 12 distinct configurations (as detailed in Table II on page 938), a clear standout has emerged. Specifically, the LSTM model featuring 32 neurons, a batch size of 10, and 50 training epochs consistently demonstrated superior predictive accuracy compared to all other parameter combinations. Notably, this configuration achieved an impressive average prediction accuracy of 99.10%, underscoring its robust performance. Moreover, the training time for this model was deemed satisfactory. Similarly, the model with 64 neurons, 50 epochs, and batch sizes of 10 and 32 yielded comparable accuracy rates of 99.01% and 99.08%, respectively. The analysis revealed that even the lowest achieved prediction accuracy was 98.03%. It's noteworthy that all 12 tested LSTM configurations yielded prediction accuracies exceeding 98%.

To provide a visual representation of our findings, Fig. 5(a) offers a comparison between predicted and actual NIFTY 50 closing price movements, along with the corresponding discrepancies. This graphical presentation effectively showcases the alignment between predicted and actual trends. Additionally, Fig. 5(c) highlights the movement in the training data and offers a comprehensive juxtaposition of predicted and actual trends. Finally, Fig. 5(b) presents a chart depicting the relationship between prediction accuracy and error, further demonstrating the model's adeptness at value estimation. Fig. 5(d) illustrates the loss vs. epoch graph for the SLSTM model that achieved the highest accuracy in predicting the movement.

TABLE II. SLSTM PREDICTION RESULTS

| Sr. | Number of Neurons in SLSTM | Batch Size | Number of Neuron in Dense Layer | Epoch | Sequence Length | Training Time | Mean Absolute Percentage Error | Prediction Accuracy |
|---|---|---|---|---|---|---|---|---|
| 1 | 16 | 10 | 16, 1 | 10 | 15 | 30.60 | 1.70 | 98.3 |
| 2 | 32 | 10 | 16, 1 | 10 | 15 | 30.14 | 1.70 | 98.30 |
| 3 | 64 | 10 | 16. 1 | 10 | 15 | 34.19 | 1.00 | 99.00 |
| 4 | 16 | 10 | 16, 1 | 50 | 15 | 148.07 | 1.10 | 98.90 |
| 5 | 32 | 10 | 16, 1 | 50 | 15 | 156.50 | 0.9 | 99.10 |
| 6 | 64 | 10 | 16, 1 | 50 | 15 | 185.01 | 0.99 | 99.01 |
| 7 | 16 | 32 | 16, 1 | 10 | 15 | 15.94 | 1.60 | 98.40 |
| 8 | 32 | 32 | 16, 1 | 10 | 15 | 15.46 | 1.40 | 98.60 |
| 9 | 64 | 32 | 16, 1 | 10 | 15 | 19.08 | 1.37 | 98.63 |
| 10 | 16 | 32 | 16, 1 | 50 | 15 | 66.77 | 1.04 | 98.96 |
| 11 | 32 | 32 | 16, 1 | 50 | 15 | 68.68 | 1.02 | 98.98 |
| 12 | 64 | 32 | 16, 1 | 50 | 15 | 87.23 | 0.92 | 99.08 |
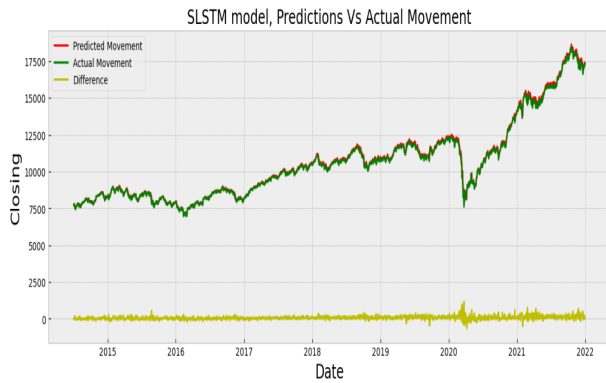


(a) Prediction vs. actual vs. difference.
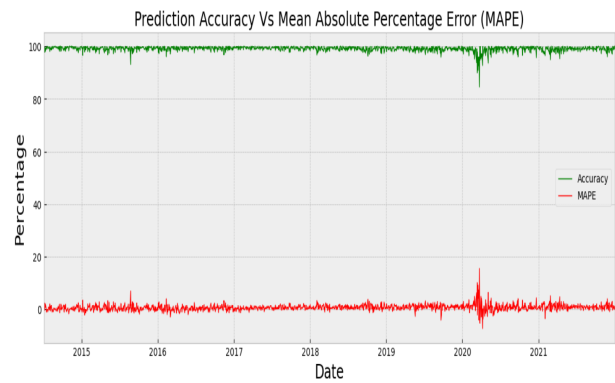


(b) Accuracy percentage vs. MAPE.
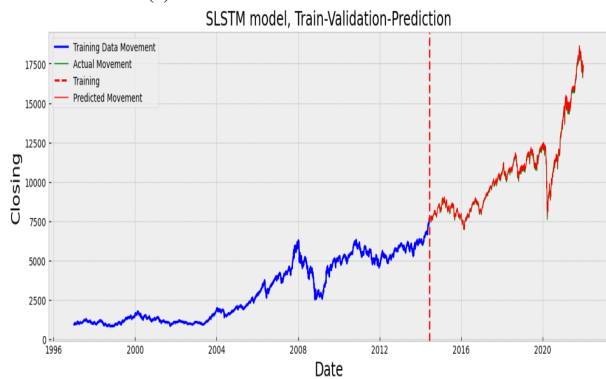


(c) SLSTM model implementation data.
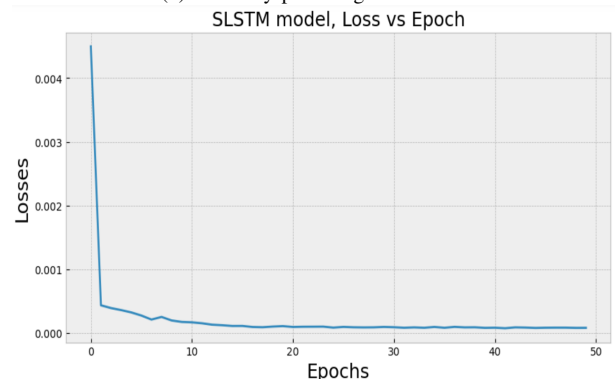


(d) Losses vs. epoch.

Fig. 5. SLSTM model testing matrix (a) Prediction vs. actual vs. difference, (b) Accuracy percentage vs. MAPE, (c) SLSTM model implementation data, (d) Losses vs. epoch.

### D. Implementation of Bidirectional Long Short-Term Memory on Nifty 50 Index Dataset

A Bidirectional LSTM, abbreviated as BiLSTM, is a sequence processing architecture composed of two LSTMs. One LSTM processes input data in the forward direction, while the other processes it in reverse. This dual approach significantly enhances the information accessible to the network, thereby enriching the contextual understanding of the algorithm. For instance, in text analysis, a BiLSTM comprehends not only the current word but also the words that follow and precede it in a sentence, amplifying its contextual awareness. The accompanying Table III on page 939 visually presents the

outcomes of our tests, offering insights into the predictive efficacy of the BiLSTM models across various configurations.

*1) Result analysis:* After a comprehensive evaluation of NIFTY 50 closing movement predictions using BiLSTM across 12 distinct configurations (as outlined in Table III on page 939), a prominent frontrunner has surfaced. Specifically, the BiLSTM model with 64 neurons, a batch size of 32, and 50 training epochs consistently exhibited superior predictive accuracy compared to all other parameter combinations. This configuration notably achieved an impressive average prediction accuracy of 96.27%, highlighting its robust performance. Additionally, the training time for this model was satisfactory.

TABLE III. BiLSTM PREDICTION RESULTS

| Sr. | Number of Neurons in BiLSTM | Batch Size | Number of Neuron in Dense Layer | Epoch | Sequence Length | Training Time (Seconds) | Mean Absolute Percentage Error | Prediction Accuracy |
|---|---|---|---|---|---|---|---|---|
| 1 | 16 | 10 | 10,5,1 | 10 | 20 | 81.76 | 20.99 | 79.01 |
| 2 | 32 | 10 | 10,5,1 | 10 | 20 | 66.44 | 47.90 | 52.10 |
| 3 | 64 | 10 | 10,5,1 | 10 | 20 | 177.06 | 51.10 | 49.90 |
| 4 | 16 | 10 | 10,5,1 | 50 | 20 | 335.74 | 12.97 | 87.03 |
| 5 | 32 | 10 | 10,5,1 | 50 | 20 | 313.74 | 13.43 | 86.57 |
| 6 | 64 | 10 | 10,5,1 | 50 | 20 | 677.32 | 45.25 | 54.75 |
| 7 | 16 | 32 | 10,5,1 | 10 | 20 | 32.86 | 7.72 | 92.28 |
| 8 | 32 | 32 | 10,5,1 | 10 | 20 | 28.88 | 4.19 | 95.81 |
| 9 | 64 | 32 | 10,5,1 | 10 | 20 | 96.95 | 4.69 | 95.31 |
| 10 | 16 | 32 | 10,5,1 | 50 | 20 | 114.81 | 4.87 | 95.13 |
| 11 | 32 | 32 | 10,5,1 | 50 | 20 | 117.90 | 6.49 | 93.51 |
| 12 | 64 | 32 | 10,5,1 | 50 | 20 | 377.99 | 3.73 | 96.27 |

However, it's worth noting that the model with 32 neurons, 10 epochs, and batch size of 10 indicated underfitting, while the model with 64 neurons, batch sizes of 10 and 32, and epochs of 10 and 50 demonstrated overfitting. These outcomes yielded prediction accuracies that were suboptimal for our NIFTY 50 trend prediction dataset.

To visually depict our conclusions, Fig. 6(a) provides a comparative view of predicted and actual NIFTY 50 closing price movements, along with discrepancies. Fig. 6(c) presents the movement in training data, effectively comparing predicted and actual trends. Fig. 6(b) offers a chart illustrating the connection between prediction accuracy and error, underscoring the model's proficiency in value estimation. Additionally, Fig. 6(d) showcases the loss vs. epoch graph for the RNN model with the highest predictive accuracy. In summary, the identified BiLSTM configuration demonstrates significant promise for NIFTY 50 trend prediction.

## IV. COMPARATIVE STUDY AND FUTURE RESEARCH OPPORTUNITIES

Based on our analysis of the RNN, SLSTM, and BiLSTM models, the SLSTM model emerged as the standout performer for predicting NIFTY 50 closing movement, achieving an impressive prediction accuracy of 99.10%. The RNN model also showcased strong predictive capabilities, yielding an average accuracy of 98.65%.

However, in contrast, the BiLSTM model did not demonstrate consistent success across various cases. In its most favorable scenario, the BiLSTM model achieved an average accuracy of 96.27%. It's noteworthy that the training time of the BiLSTM model was comparatively higher when compared to SLSTM and RNN. Additionally, the BiLSTM model was more susceptible to issues of both underfitting and overfitting. In summary, the SLSTM model showcased remarkable predictive prowess, while the RNN model also performed well. On the other hand, the BiLSTM model faced challenges and did not consistently match the accuracy levels achieved by the other two models. Fig. 7(a) illustrates the comparison of predicte values, while Fig. 7(b) depicts the accuracy of predicted movements of the models.

This study has advanced our understanding of stock market prediction but also highlights several promising directions for future research. Enhancing prediction accuracy through the refinement of existing models, including the integration of external data sources, is a key avenue. Exploring alternative deep learning architectures and hybrid models holds potential for improved results. Moreover, incorporating sentiment analysis from various sources such as financial news, social media, and macroeconomic factors can offer a more comprehensive understanding of market movements. Investigating the interpretability of deep learning models and their capacity to capture underlying market dynamics is essential for their practical acceptance and use in the real world.

## V. CONCLUSION

After a thorough exploration of diverse algorithms, we have uncovered their significant relevance within stock markets. Given the intricate interplay of factors shaping stock market dynamics, there exists a compelling opportunity to refine and elevate the algorithms and models employed for predicting stock prices. Our comparative analysis has illuminated the robust performance of deep learning models, including LSTM, ANN, RNN, SLSTM, and BiLSTM, in efficiently forecasting stock prices with minimal errors. To delve deeper, we focused on implementing RNN, SLSTM, and BiLSTM deep learning models within this study, harnessing a comprehensive 27-year dataset of NIFTY 50 data as our input. Our methodology allocated 70% of the dataset for model training, reserving the remaining 30% for validation purposes.

During the validation phase, our findings emphatically underscored the superior predictive capabilities of the SLSTM model. It consistently outperformed the other three models in accurately predicting the closing movement of the NIFTY 50 index, achieving an impressive average accuracy of 99.10%. Our analysis further unveiled captivating behaviors inherent in deep learning models, presenting avenues for subsequent exploration and model refinement. By enhancing the consistency of error patterns and elevating accuracy, these models' efficacy can be further amplified. Furthermore, our research lays the groundwork for extending prediction prowess to both short-term and long-term future movements. The scope of its applicability can be expanded to encompass stock prices within other sectors, thereby fostering new realms of inquiry.

## REFERENCES

[1] X. Huang, "Portfolio selection with a new definition of risk," *European Journal of Operational Research*, 2008. [Online]. Available: https://doi.org/10.1016/j.ejor.2007.01.045

(a) Prediction vs. actual vs. difference.



(b) Accuracy percentage vs. MAPE.



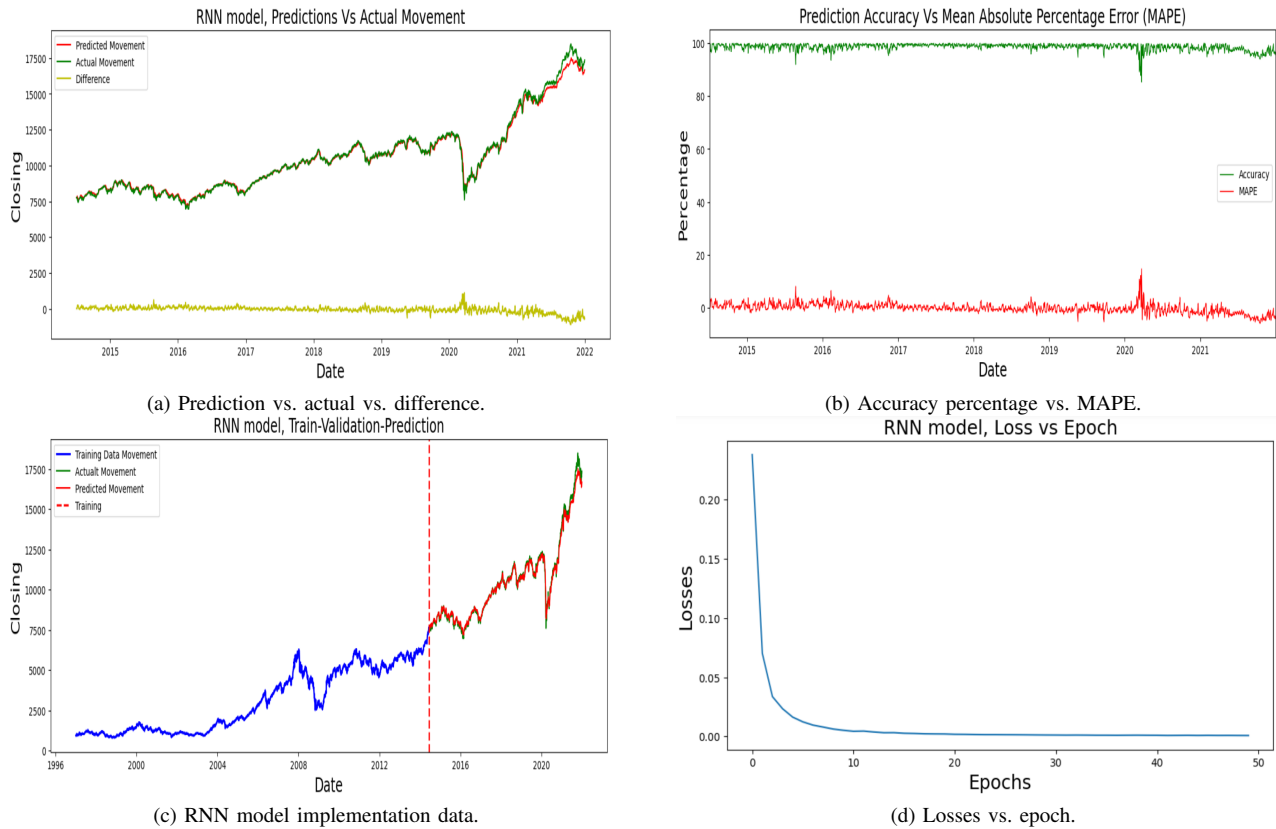(c) BiLSTM model implementation data.
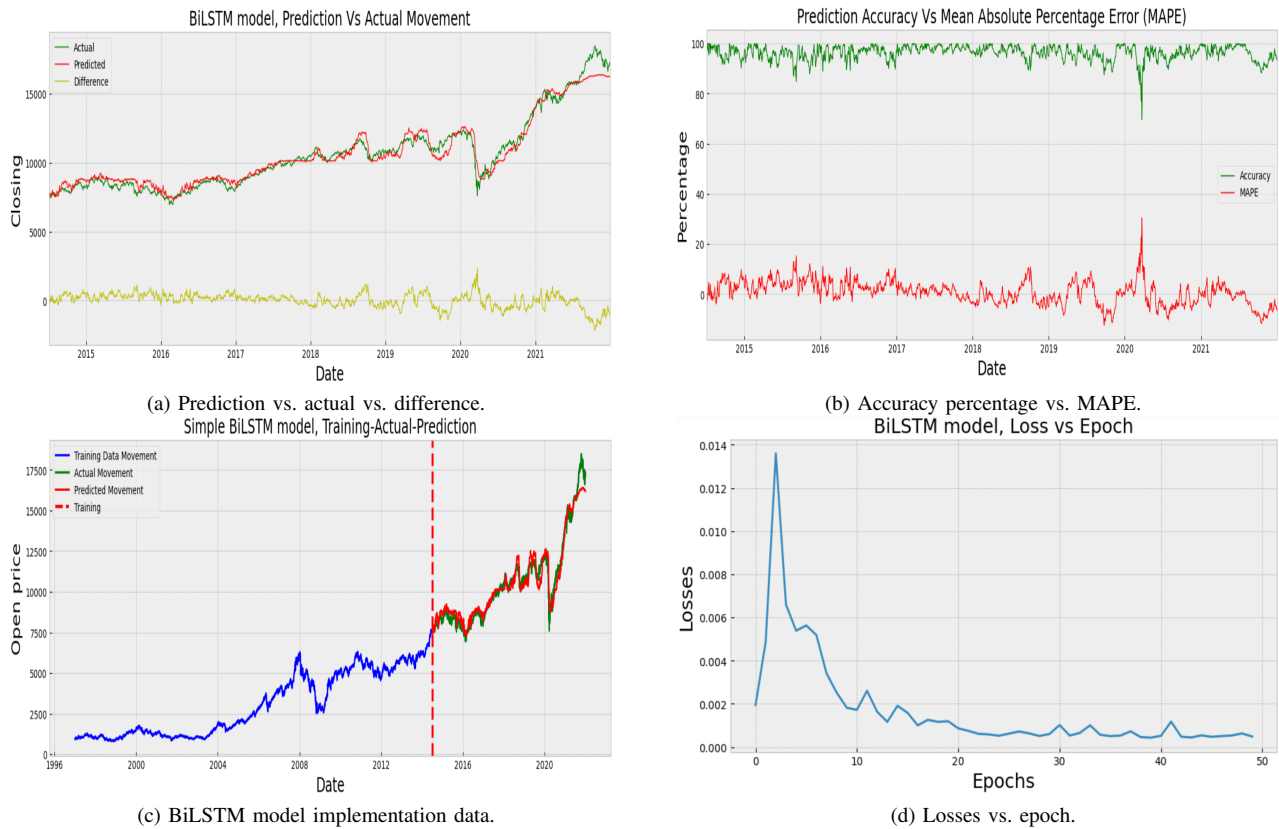


(d) Losses vs. epoch.

Fig. 6. BiLSTM model testing matrix (a) Prediction vs. actual vs. difference, (b) Accuracy percentage vs. MAPE, (c) SLSTM model implementation data, (d) Losses vs. epoch.



(a) RNN vs. SLSTM vs. BiLSTM prediction.



(b) RNN vs SLSTM vs BiLSTM prediction accuracy.
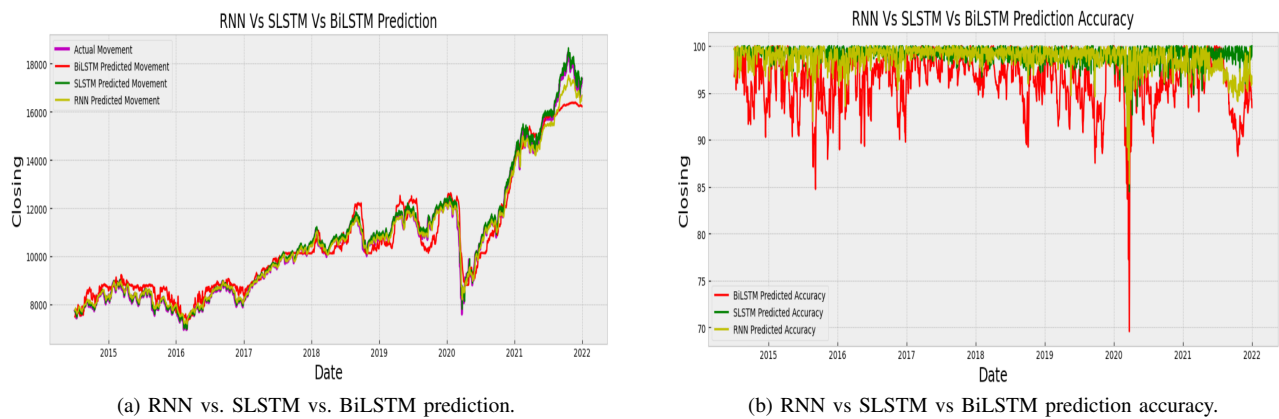
Fig. 7. (a) RNN vs. SLSTM vs. BiLSTM prediction, (b) RNN vs. SLSTM vs. BiLSTM prediction accuracy.

[2] A. Farooq and P. Chawla, "Review of data science and ai in finance," in *2021 International Conference on Computing Sciences (ICCS)*. IEEE, 2021, pp. 216–222. [Online]. Available: https://doi.org/10.1109/ICCS54944.2021.00050

[3] P. D. Yoo, M. H. Kim, and T. Jan, "Machine learning techniques and use of event information for stock market prediction: A survey and evaluation," vol. 2, 2005. [Online]. Available: https://doi.org/10.1109/CIMCA.2005.1631572

[4] K.-j. Kim and I. Han, "Genetic algorithms approach to feature discretization in artificial neural networks for the prediction of stock price index," *Expert systems with Applications*, vol. 19, no. 2, pp. 125–132, 2000. [Online]. Available: https://doi.org/10.1016/S0957-4174(00)00027-0

[5] M. Qiu and Y. Song, "Predicting the direction of stock market index movement using an optimized artificial neural network model," *PloS one*, vol. 11, no. 5, p. e0155133, 2016.

[6] M. R. Hassan and B. Nath, "Stock market forecasting using hidden markov model: a new approach," in *5th International Conference on Intelligent Systems Design and Applications (ISDA'05)*. IEEE, 2005, pp. 192–196.

[7] M.-C. Lee, "Using support vector machine with a hybrid feature selection method to the stock trend prediction," *Expert Systems with Applications*, vol. 36, no. 8, pp. 10 896–10 904, 2009. [Online]. Available: https://doi.org/10.1016/j.eswa.2009.02.038

[8] J. Sirignano and R. Cont, "Universal features of price formation in financial markets: perspectives from deep learning," *Quantitative*

*Finance*, vol. 19, no. 9, pp. 1449–1459, 2019. [Online]. Available: https://doi.org/10.2139/ssrn.3141294

[9] L.-P. Ni, Z.-W. Ni, and Y.-Z. Gao, "Stock trend prediction based on fractal feature selection and support vector machine," *Expert Systems with Applications*, vol. 38, no. 5, pp. 5569–5576, 2011. [Online]. Available: https://doi.org/10.1016/j.eswa.2010.10.079

[10] S. McNally, J. Roche, and S. Caton, "Predicting the price of bitcoin using machine learning," in *2018 26th euromicro international conference on parallel, distributed and network-based processing (PDP)*. IEEE, 2018, pp. 339–343. [Online]. Available: https://doi.org/10.1109/PDP2018.2018.00060

[11] B. Weng, L. Lu, X. Wang, F. M. Megahed, and W. Martinez, "Predicting short-term stock prices using ensemble methods and online data sources," *Expert Systems with Applications*, vol. 112, pp. 258–273, 2018. [Online]. Available: https://doi.org/10.1016/j.eswa.2018.06.016/

[12] Y. Kara, M. A. Boyacioglu, and Ö. K. Baykan, "Predicting direction of stock price index movement using artificial neural networks and support vector machines: The sample of the istanbul stock exchange," *Expert systems with Applications*, vol. 38, no. 5, pp. 5311–5319, 2011. [Online]. Available: https://doi.org/10.1016/j.eswa.2010.10.027

[13] X. Li, Y. Li, H. Yang, L. Yang, and X.-Y. Liu, "Dp-lstm: Differential privacy-inspired lstm for stock prediction using financial news," *arXiv preprint arXiv:1912.10806*, 2019. [Online]. Available: https://doi.org/10.48550/arXiv.1912.10806

[14] S. Mehtab, J. Sen, and A. Dutta, "Stock price prediction using machine learning and lstm-based deep learning models," in *Machine Learning and Metaheuristics Algorithms, and Applications: Second Symposium, SoMMA 2020, Chennai, India, October 14–17, 2020, Revised Selected Papers 2*. Springer, 2021, pp. 88–106. [Online]. Available: https://doi.org/10.48550/arXiv.2009.10819

[15] H. NekoeiQachkanloo, B. Ghojogh, A. S. Pasand, and M. Crowley, "Artificial counselor system for stock investment," in *Proceedings of the AAAI conference on artificial intelligence*, vol. 33, no. 01, 2019, pp. 9558–9564. [Online]. Available: https://doi.org/10.48550/arXiv.1903.00955

[16] M. Nabipour, P. Nayyeri, H. Jabani, A. Mosavi, and E. Salwana, "Deep learning for stock market prediction," *Entropy*, vol. 22, no. 8, p. 840, 2020. [Online]. Available: https://doi.org/10.3390/e22080840

[17] M. Hiransha, E. A. Gopalakrishnan, V. K. Menon, and K. Soman, "Nse stock market prediction using deep-learning models," *Procedia computer science*, vol. 132, pp. 1351–1362, 2018. [Online]. Available: https://doi.org/10.1016/j.procs.2018.05.050

[18] M. R. Vargas, B. S. De Lima, and A. G. Evsukoff, "Deep learning for stock market prediction from financial news articles," in *2017 IEEE international conference on computational intelligence and virtual environments for measurement systems and applications (CIVEMSA)*. IEEE, 2017, pp. 60–65. [Online]. Available: https://doi.org/10.1109/CIVEMSA.2017.7995302

[19] Q. Liu, Z. Tao, Y. Tse, and C. Wang, "Stock market prediction with deep learning: The case of china," *Finance Research Letters*, vol. 46, p. 102209, 2022. [Online]. Available: https://doi.org/10.1016/j.frl.2021.102209

[20] S. Mukherjee, B. Sadhukhan, N. Sarkar, D. Roy, and S. De, "Stock market prediction using deep learning algorithms," *CAAI Transactions on Intelligence Technology*, vol. 8, no. 1, pp. 82–94, 2023. [Online]. Available: https://doi.org/10.1049/cit2.12059

[21] Y. Zhao and G. Yang, "Deep learning-based integrated framework for stock price movement prediction," *Applied Soft Computing*, vol. 133, p. 109921, 2023. [Online]. Available: https://doi.org/10.1016/j.asoc.2022.109921

[22] A. Q. Md, S. Kapoor, C. J. AV, A. K. Sivaraman, K. F. Tee, H. Sabireen, and N. Janakiraman, "Novel optimization approach for stock price forecasting using multi-layered sequential lstm," *Applied Soft Computing*, vol. 134, p. 109830, 2023. [Online]. Available: https://doi.org/10.1016/j.asoc.2022.109830

[23] A. Dezhkam and M. T. Manzuri, "Forecasting stock market for an efficient portfolio by combining xgboost and hilbert-huang transform," *Engineering Applications of Artificial Intelligence*, vol. 118, p. 105626, 2023.

[24] L. Zhang, C. Aggarwal, and G.-J. Qi, "Stock price prediction via discovering multi-frequency trading patterns," in *Proceedings of the 23rd ACM SIGKDD international conference on knowledge discovery and data mining*, 2017, pp. 2141–2149. [Online]. Available: https://doi.org/10.1145/3097983.3098117

[25] G. Li, A. Zhang, Q. Zhang, D. Wu, and C. Zhan, "Pearson correlation coefficient-based performance enhancement of broad learning system for stock price prediction," *IEEE Transactions on Circuits and Systems II: Express Briefs*, vol. 69, no. 5, pp. 2413–2417, 2022. [Online]. Available: https://doi.org/10.1109/TCSII.2022.3160266

[26] S. Banik, N. Sharma, M. Mangla, S. N. Mohanty, and S. Shitharth, "Lstm based decision support system for swing trading in stock market," *Knowledge-Based Systems*, vol. 239, p. 107994, 2022. [Online]. Available: https://doi.org/10.1016/j.knosys.2021.107994

[27] Z. K. A. Bodie and A. J. Marcus, *Investments and portfolio management*. McGraw Hill Education (India) Private Limited, 2013.

[28] D. Spahija and S. Xhaferi, "Fundamental and technical analysis of the stock price," *International Scientific Journal Monte*, vol. 1, 2019. [Online]. Available: https://doi.org/10.33807/monte.1.201904160

[29] M. Sundermeyer, R. Schlüter, and H. Ney, "Lstm neural networks for language modeling," in *Thirteenth annual conference of the international speech communication association*, 2012. [Online]. Available: https://doi.org/10.1016/j.physd.2019.132306

**Disclaimer: This analysis is for research purposes only and should not be considered as trading recommendations; individuals who choose to do so assume their own risk for potential losses.**

# Detection of Dyslexia Through Images of Handwriting using Hybrid AI Approach

Norah Dhafer Alqahtani[1], Bander Alzahrani[2], Muhammad Sher Ramzan[3]

Faculty of Computing and Information Technology, King Abdulaziz University, Jeddah 21589, Saudi Arabia[1,2,3]

Information Systems, King Khaled University, Abha 61421, Saudi Arabia[1]

*Abstract*—Dyslexia is a neurodevelopmental disorder characterized by difficulties with acquiring reading skills, despite the presence of appropriate learning opportunities, sufficient education, and a suitable sociocultural context. Dyslexia negatively affects children's educational development and their acquisition of language, as well as their writing. Therefore, early detection of dyslexia is of great importance. The prediction of dyslexia through handwriting is an active research field of almost five years' standing. In this paper, we propose hybrid models (CNN-SVM) and (CNN-RF) to reveal dyslexia through images of handwriting. The paper aimed to develop a CNN model to extract features from images of handwriting where CNN is highly reliable in extracting features from images, and to use SVM as a classifier due to its generalization abilities as well as using random forest (RF) as a classifier in (CNN-RF). The study aimed to combine a deep learning (DL) model and a machine learning (ML) model to improve model performance. Data sets that consisted of 176,673 images of handwriting were used in this study. The hyperparameter of the model was adjusted and examined in order to classify the three categories of handwriting. The CNN model that was built demonstrated an outstanding accuracy rate of 98.71% in effectively categorizing three distinct types of handwriting—99.33% with SVM, and 98.44% in the CNN-RF model. The aim of recognizing dyslexic handwriting through CNN-SVM was successfully attained, and our model outperformed all previous models.

*Keywords—Dyslexia; dyslexia detection; deep learning; dyslexia classification; CNN model; SVM model; random forest model*

## I. INTRODUCTION

Dyslexia is a language-based, neurobiological, developmental learning disorder that affects how people learn to read (in terms of accuracy and speed) and how they learn to spell. As a result of impairments in the phonological component of language, individuals with dyslexia struggle to connect spoken language with the written word [1]. Difficulty accurately and fluently deciphering words can impact reading and vocabulary development [2].

Although dyslexia is neither a sign nor an indicator of low intelligence, it may cause a person to perform poorly academically and to become frustrated. A person may drop out of education entirely. Detecting dyslexia in children as early as possible and using assistance tools and intervention programs may improve their skills and learning performance. In recent years, a greater awareness of dyslexia and other learning difficulties has developed.

Traditional diagnostic tools and tests have been used to detect these disorders and assist individuals based on the results of diagnostic tests. These detection techniques have focused on behavioural elements, such as proficiency in reading and writing and working memory and have also included IQ tests.

They are generally standardized tests [3]. Since every individual with dyslexia has a unique experience of the disorder, this approach can be time-consuming and runs the risk of missing cases or providing inaccurate diagnoses. Traditional machine learning methods and deep learning algorithms are being increasingly used in dyslexia and biomarker detection and have proven their effectiveness in making diagnoses. One of the deep learning models is Convolutional Neural Network (CNN), which has the ability to deal with images and extract features from them. This paper aims to enrich research in this field; our study is considered the sixth study in predicting dyslexia by looking at handwriting using DL models. In addition, the study developed CNN model to raise its ability in extracting features. Moreover, It builds hybrid models based on CNN; (CNN-SVM and CNN-RF) for developing dyslexia detection through the use of machine learning (ML) and deep learning (DL). Better classification accuracy can be achieved when the DL and ML models are combined than when they are used separately, as noted in [4], where the first (DL) can automatically extract useful spatial characteristics, while the second (ML) can classify the features that have been extracted by DL mode (CNN) . The paper is organized into five sections: Section II details the related work, noting studies that have examined the detection of dyslexia through children's handwriting and their key results. Section III introduces the phases that will be followed in this study, Section IV presents suggested models that will be used in this study. Section V illustrates the steps of the experiment, starting from data set acquisition to classification phase. Section VI explores the results of this study. Section VII is the conclusion.

## II. RELATED WORK

The advent of AI and its various capabilities have opened up possibilities for automating methods of diagnosis and early detection of dyslexia through the use of ML and DL. Existing methods of detecting dyslexia have included detection using Magnetic Resonance Imaging (MRI), Electroencephalogram (EEG) signals, and eye-tracking, as well as Electrooculogram (EOG) signals. The ML method and computer vision can help with dyslexia classification as illustrated in [5]. Although earlier methods achieved good accuracy, it was time-consuming and expensive to collect the required neurological data. Dyslexic children have irregular handwriting and reverse their letters. This feature (inverted letters) helped Spoon et al. [3] to look at a new method for dyslexia prediction¬—the use of images of handwriting. They attempted to collect samples to investigate if there was a possibility of diagnosing dyslexia through handwriting samples using the CNN model. They achieved 55.71.4% accuracy on average—better than

the random standard of 50%. These preliminary outcomes nevertheless showed promise, with the detection rate much higher than that able to be achieved by instructors and parents at that time. These results encouraged researchers and led them to prove this concept in their study [6]. They used 100 samples of handwriting and built CNN models for prediction. The result was 77.6%—higher than the previous result. In another study, Isa et al. developed an automated handwriting recognition framework using an image-processing and pattern-recognition technique through the use of MATLAB to build an Artificial Nural Network (ANN) model—a method for processing information that was inspired by how biological neural systems process information [7]. The study employed four letters—'f,' 'p,' 'b,' and 'c'—as well as four numbers—'5,' '2,' '6,' and '7'. These samples were chosen because dyslexic people are often confused about the shape of these figures. The samples were used to train and test a suggested model —ANN—to extract features from images and utilized MLP as a features classifier. The model achieved accuracy of 73.33%, which was still considered low, due to the lack of samples. This study was followed by an Indian study that aimed to determine whether it was possible to detect dyslexia in Indian handwriting [8]. The researchers were able to collect approximately 267 pictures from the participants' textbooks and process them. The CNN model was used to extract features from the images and predict dyslexia in children; here it was able to automatically find strong features by using Keras and TensorFlow—the accuracy average was 86.14%. All previous studies suffered from the small-scale size of the data sets and the problem of an imbalanced class, which affected the performance of the DL models as well as well as their tend to the large-scale class. In the study [9] researchers put more effort into building a dyslexia data set that could be utilized by other researchers in the future, they used these data sets to build different CNN models to compare the performance of these models. They employed data augmentation techniques to maximize the scale of data sets and solve the class imbalance problem. Different CNN models, like CNN-1, CNN-2, CNN-3, and LeNet-5, were used and compared in this study. The CNN-1 model achieved high accuracy compared with other models, which reached 87% in the classification process. The transfer learning technique was used to develop the performance of the DL model for classification purposes in [1]. The study utilized the same data set as the previous study and built a CNN model based on the well-known handwriting detection architecture of LeNet-5. The suggested model achieved an outstanding accuracy of 95.34% in the three classes of classification. These studies have some limitations which illustrated in Table I.

This study presents the following contributions: (i) Develop the CNN model to raise its performance in feature extraction from the handwriting model; (ii) assessing the performance of SVM and RF classifiers, as well as a CNN classifier, in terms of their ability to utilize CNN feature extraction for improving diagnosis accuracy. These models will use the dataset that has been used by the last two studies after removing the redundancy from it, and the classes will be balanced.

## III. METHODOLOGY

The study passes through three phases: the first phase relates to data preprocessing and dividing the dataset (training, validation, and testing) before used by the CNN model. In the second stage, the CNN model will be built and used a dataset that has been processed in phase 1(training, validation) to train the model in extracting features from the handwriting images till reach the required accuracy. In the last stage, training and validation data will be used as one data set to train the different classifiers, then test data will be used to test the performance of different classifiers. Fig. 1The workflow of the proposed method. illustrates the workflow of this study. The primary objective of the research is to introduce and evaluate hybrid models, specifically (CNN-SVM) and (CNN-RF), for the effective detection of dyslexia through images of handwriting. The research leverages Convolutional Neural Networks (CNN) to extract meaningful features from the handwriting images, exploiting the well-known reliability of CNNs in image feature extraction. In addition, Support Vector Machines (SVM) are chosen as classifiers due to their strong generalization capabilities. The (CNN-RF) model introduces Random Forest (RF) as an alternative classifier, enriching the model diversity. This hybrid approach combines deep learning (DL) models, such as CNN, with machine learning (ML) models like SVM and RF, with the intention of enhancing overall model performance.

## IV. SUGGESTED APPROACHES

The study suggested hybrid models based on CNN model for classifying data in this study (CNN-SVM and CNN-RF). In addition, developing CNN model that have been used in the literature to raise its ability in extracting features and the raise the performance in the prediction of dyslexia.

### A. Convolutional Neural Network

The CNN model is a DL technique that is specifically designed for the task of image classification. It operates on two-dimensional (2D) images as input data. Similar to ANNs, the CNN model exhibits a hierarchical architecture consisting of multiple layers, where the output of each preceding layer is systematically linked to the input of the subsequent layer. A traditional ANN structure is paired with a stage for extracting spatial features using a sequence of convolutional filters [4]. The architectural design of the CNN model typically encompasses three primary, interconnected layers—namely, the convolutional layer, pooling layer, and fully connected layer. The initial step in the convolutional layer involves the computation of weights through the application of a convolution filter. This filter performs a dot product operation on either the 2D input data or the outputs of preceding layers within a localized region [4]. Feature maps are generated by using a nonlinear activation function, such as a Sigmoid, Tanh and Rectified Linear Unit (ReLU), which is what was utilized in this study. The pooling layer is utilized to condense the retrieved features into representative values, such as maximum or mean values, in order to simplify the information. The utilization of the max pooling layer has been extensively employed in the classification process of CNNs [10]. The two layers (convolutional and pooling) are sequentially arranged in an alternating manner until higher-level features are obtained. Once the convolutional and pooling processes have been performed to extract the high-level features, the resulting feature maps are converted into a one-dimensional vector and subsequently passed to the fully connected layer. Typically, the final, fully connected

TABLE I. LIMITATIONS OF THE RELATED WORKS

| Study | Limitation |
|---|---|
| [3] | 1) They achieved 55.7% accuracy, and the baseline was 50%, there was no significant improvement.<br>2) To improve the outcomes, more data are needed, particularly data from dyslexic pupils. |
| [6] | 1) They achieved 77.6% accuracy results, still, there is a chance to improve it.<br>2) Their dataset consists of 100 samples, which are considered small-scale data. CNN does not perform well with small-scale data. |
| [7] | 1) The data set is small and focused on specific small letters 'b', 'c', 'f', 'p'.<br>2) The performance of the classification accuracy does not exceed 75%. This is because the ANN needs a lot of samples to get high. |
| [8] | 1) In this study, the letters are cropped manually, which required improvement, Handwritten recognition by using (OCR) can be used, or cursive and skew methods.<br>2) The dataset used in the experiments is small. More data is required to study the results further. |
| [9] | 1) The imbalance class problem is still in this study although data augmentation techniques have been applied, in addition to the presence of some duplicate images in the dataset.<br>2) The study requires more dyslexic handwriting images for the test set (real dataset) in examining the performance of the model. |
| [10] | 1) The imbalance class problem is still in this study although data augmentation techniques have been applied, in addition to the presence of some duplicate images in the dataset.<br>2) Other data augmentation techniques can be applied where the study focused on the rotation technique. The transfer learning effectiveness from sources was not explained well.<br>3) It can be improved classification tasks by using other methods and rise the model performance. |

layer of a neural network is responsible for normalizing the network's output. This normalization process involves utilizing a SoftMax function to get probability values corresponding to the expected output classes. Ultimately, the categorization outcome is determined through the use of the maximum probability rule [4]. CNN has produced outstanding results in the field of computer vision and pattern recognition [11], for example in visual recognition [12], image retrieval [13], and scene annotation [14]. This model has been effectively implemented for character recognition in handwritten images. It has been successfully used in offline, handwritten Javanese character recognition [15]. In the study [12], CNN achieved 88% in the Arabic data set, and high accuracy in MODI (ancient Indian script) character recognition [16]. According to [17], modifying the CNN with two different types of training input—reconstruction feedback and classification feedback—was able to achieve an accuracy rate of 99.59% on the MNIST data set. Some of the research tweaks CNN in a number of ways to improve its performance and accuracy rate. Other research alters the input data to enhance the accuracy rate of the CNN model.

### B. Support Vector Machine

SVM is a supervised learning model with corresponding learning algorithms that analyze data utilized for classification and analysis of regression. This model is considered one of the most solid prediction methods, which depend on statistical learning frameworks. It can be utilized to solve different problems in the real world; for example, it is useful in the categorization of text and hypertext, the recognition of handwritten characters [18], face detection, and satellite data classification. There are two kinds of SVM: linear and nonlinear. The first is utilized for linearly separable data. A data set is said to be linearly separable if it can be divided into two classes using a single straight line; the classifier used is known as a linear SVM classifier. However, if the data set cannot be classified using a straight line, such data is known as nonlinear data, and the classifier applied is called nonlinear. The basic idea of SVM is to get the best hyperplane, which maximizes the hyperplane margin. A good generalization is achieved by a hyperplane with a maximum margin.

CNN is an extension model of multilayer perceptrons (MLP), since its theoretical learning technique is the same as MLPs'. The MLP learning algorithm tries to reduce errors in the training set: it depends on empirical risk minimization (ERM). When the backpropagation method discovers the first separating hyperplane, whether it is a global or local minima, the training operation ends. The MLP learning algorithm does not continue to enhance the separating hyperplane solution. Further, the SVM classifier utilizes a structural risk minimization (SRM) precept on unseen data to minimize the errors of generalization, with a constant distribution for the training set [19]. Therefore, SVM generalization ability is much better than that of MLP. According to [20]–[23], the SVM method has high generalization performance, which means it can correctly classify data that has never been seen before. One paper [24] advised using the SVM classifier as an end classifier because it has better generalization ability than neural networks on standard CNN.

### C. Random Forest

RF is widely utilised in the field of machine learning and falls under the category of supervised learning techniques. ML can utilise this technique for both regression and classification tasks. The approach is rooted in the principle of ensemble learning, wherein many classifiers are integrated to address intricate problems and enhance the model's performance [25]. The classifier known as "Random Forest" is so named because it consists of many decision trees that are constructed using different subsets of the provided dataset. By taking the average of the predictions made by these decision trees, the RF classifier aims to enhance the accuracy of its predictions for the supplied dataset. The random forest algorithm utilises an ensemble approach by aggregating predictions from several decision trees. By considering the majority vote among these predictions, the random forest algorithm generates the final output. We chose these classifiers for this study for two reasons: previous studies relied on this CNN classifier to classify dyslexia, and its use here after its development shows an increase in the performance of the model compared to the previous one. In addition, RF is considered an effective and robust algorithm due to the avoidance of over-fitting, its high level of accuracy of classification, its ability to assess the
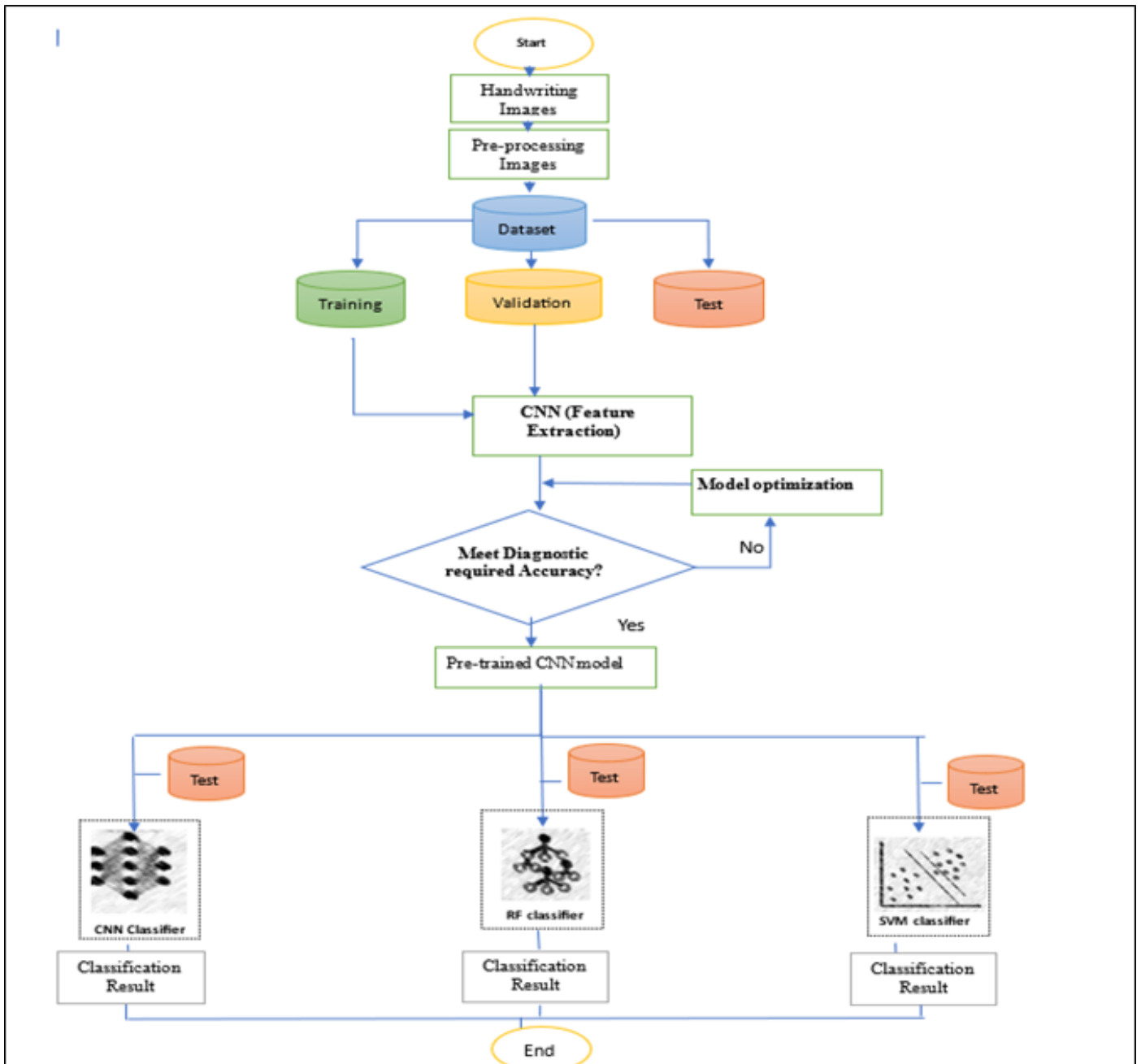
Fig. 1. The workflow of the proposed method.

relevance of variables [26] and its ability to operate effectively on huge databases [27] as well as the ability of SVM in generalization as we explained before.

## V. EXPERIMENT

### A. Data Set Used

The data set used in this study was images of the handwriting of three classes: reversal (dyslexics), normal, and corrected handwriting suggested by Susan Barton, founder of Bright Solutions for Dyslexia [28]. This data is publicly available in [29] which is obtained from three distinct sources. The uppercase letters were sourced from the NIST Special Database 19 [30] while the lowercase letters were obtained from the Kaggle data set [31]. Additionally, certain data sets for testing purposes were collected from dyslexic students attending Seberang Jaya primary school by researchers in [9]. This data set consisted of 176,673 images. In the context of the reversal class, the normal handwriting data set underwent a mirroring process, resulting in the creation of reversal data sets through horizontal flipping as mentioned in study [9] as well as apply rotation and noise injection techniques after horizontal flipping. This data set has been used by the last two studies in this field [9], [1]. Samples of this data set are shown in Fig. 2Samples of datasets used., where A is a sample of the reversal class, B is a sample of the normal class, and C is sample of

corrected writing.

### B. Pre-processing

The data sets needed to be processed before feeding the classifier by them. A foreground-background swap was adopted to reduce computational overhead, as training an image with more white points (value 1) than black points (value 0) consumes more power and memory [32]. This procedure alters the background color to black while leaving the handwriting white. The subsequent action is the process of cropping the image to isolate the section containing the written content. This procedure involves the removal of undesired sections of an image, specifically from the bottom and top, and the right and left sides. The resulting image will be centered on the alphabet, thereby emphasizing it. In our study, the photos underwent a resizing process to dimensions of 32×32 pixels, ensuring uniformity across all data sets. This was done to facilitate their use as input for the CNN model. Ultimately, the entire data set was converted into a .csv file based on the one-hot encoding technique. The data sets were divided into 70% handwriting data sets for training objectives, 15% for validation, and 15% for testing objectives.

### C. Feature Extraction

Feature extraction from the handwriting data sets was done through the CNN layers, which consisted of four convolutional layers, two max-pooling layers, and a flattened layer. Fig. 2 shows these layers. Convolutional layers act as a feature extractor; they receive the feature representations of the input pictures, and the trainable convolutional kernel adjusts its kernel weights automatically during the backpropagation training process [33], [34]. The pooling layer works to alter the input feature into a statistical picture of the surrounding feature, hence making the next feature smaller than the one before it [34]. As shown in Fig. 3, a batch normalization layer subsequent to each convolutional layer is suggested. This is used in neural networks to normalize the activation values of hidden units. Normalization ensures that the activations maintain consistent behavior during training, leading to improved accuracy and faster training [35]. Moreover, to prevent overfitting of the model, we utilized a dropout layer, which implements a regulatory mechanism wherein a subset of neurons is randomly disregarded during the training process. After being built, the model required fine tuning to raise performance and therefore accuracy in the training data sets. According to our objectives in the three class classifications to predict dyslexia, we preferred to utilize the RLU as an activation function, as it addresses the issue of gradient vanishing that arises due to the utilization of sigmoid and tanh activation functions in deep neural networks [36]. Moreover, it enhances the intricacy of the neural network by incorporating non-linearity, hence enabling the network to acquire more intricate representations of the data, thereby increasing the performance of the model. The features extraction vector has generated from the convolution operation, the pooling operation as well ReLU function, as shown below equation,

$$O_{x,x} = \sum_x \sum_y f[l,k] * [x-l][y-k]$$
$$F_{x,y} = \max(0, F\_O_{x,y})$$

(1)

The handwriting images are fed via CNN layers starting from convolutional layer for extracting significant features. The given input consists of a two-dimensional matrix with a rank of 2. The matrix has M rows and N columns, where the indices for the rows and columns are denoted as (x, y). It is important to note that the values of x and y should satisfy the condition $0 \le x \le M$ and $0 \le y \le N$. The convolutional operation layer produces the final feature map values, denoted as Fx,y which are deemed to be significant for the task at hand. The utilization of an activation function is implemented at every layer in order to enable the model to effectively address nonlinear problems, as demonstrated in Eq. 1. Additionally, the incorporation of dropout and max pooling techniques serves to reduce the computing burden associated with the model.

The Adam optimizer was also used; the Adam optimization technique has gained wider acceptance in recent years for its application in deep learning tasks related to computer vision and natural language processing. It combines the advantages of AdaGrad and the RMSProp optimizer. One of the setup parameters utilized in the Adam optimization algorithm is the learning rate, which is assigned a value of 0.001. The last feature map undergoes a transformation so as to be represented as a vector with a single column. The recognition experiment involves feeding a single-column feature vector, which consists of identifiable features, to the classifier (a soft max layer of CNN, SVM, and RF) as shown in Fig. 3.

### D. Classification

Following the completion of the pre-processing and feature extraction procedures, we classified the handwritten digit images using the different classifiers. Different classifiers were trained by utilizing feature vectors stored in a matrix format. The evaluation of the numerical value was conducted using the outcomes obtained from the training process. The hyperparameter of SVM employed an RBF function as its kernel, the cost parameter C = 1 and degree = 3. The RF was used to evaluate the model classification with hyperparameter (n_estimators), which was equal to 50 in this study, and to evaluate classifications with a fully connected layer in the CNN with a batch size = 64 and number of epochs = 40.

### VI. RESULTS DISCUSSION AND OBSERVATIONS

In this section we evaluate the performance of the three models: the CNN model, the CNN-RF model, and the CNN-SVM model.

Loss and accuracy: The evaluation of a CNN model's performance in extracting features is determined by measuring the loss and accuracy on both the training and validation data sets. The testing dataset will be used in classification stage after the training all classifier as we explained in methodology section. The analysis and interpretation of this loss value provide insights into the model's effectiveness on these two sets. The error aggregation is computed as the cumulative aggregate of errors made for each individual example within the training or validation sets. The loss value refers to the degree of performance exhibited by a model following each iteration of optimization. As seen in Fig. 4Loss of a CNN model., the training loss in the CNN model was 0.0407, while the validation loss was 0.0384.
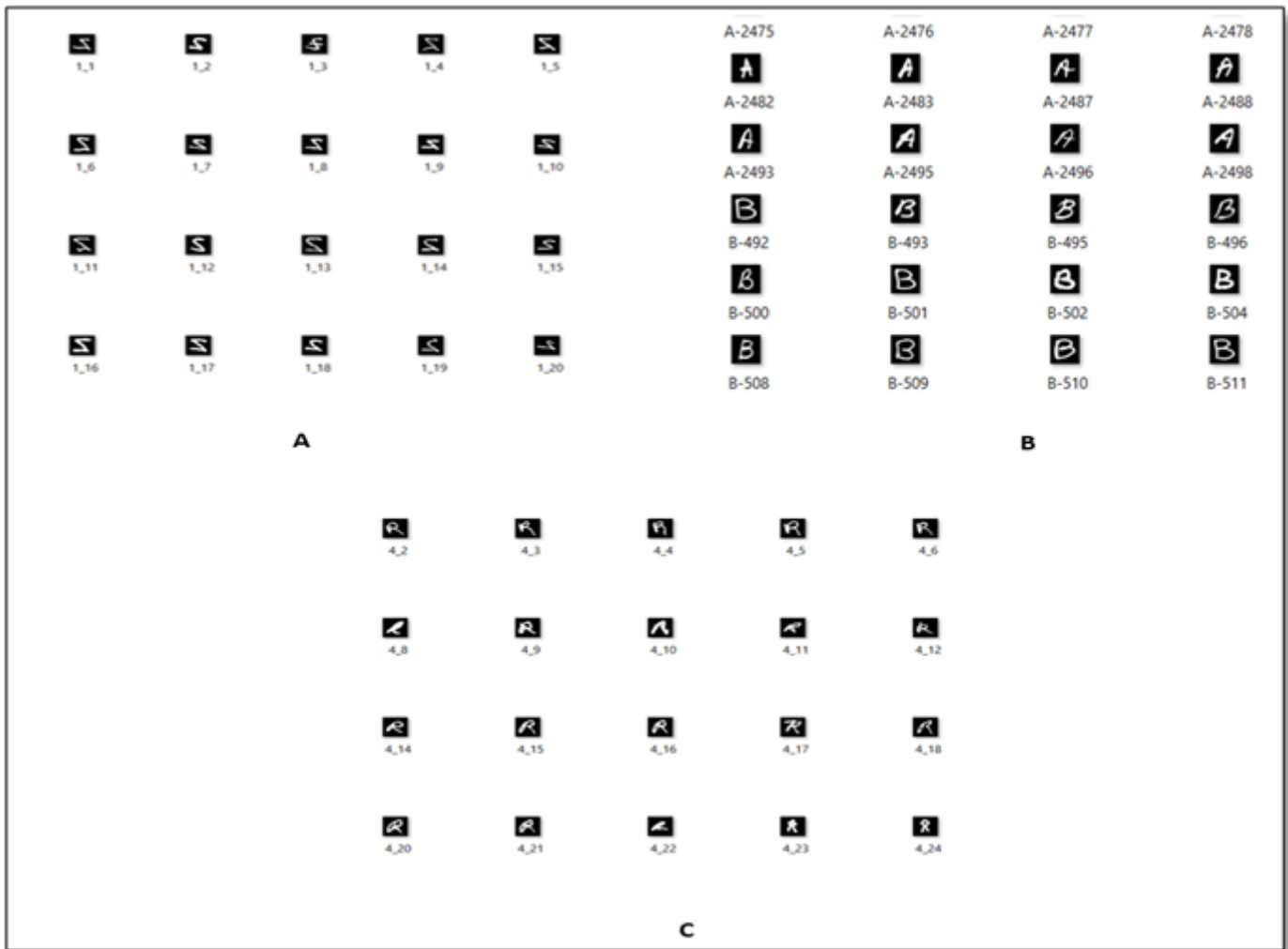
Fig. 2. Samples of datasets used.
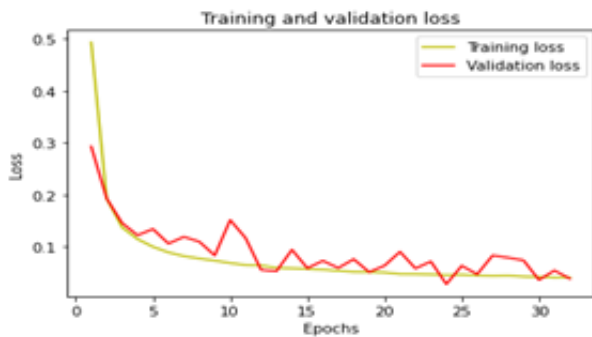


Fig. 4. Loss of a CNN model.



Fig. 5. Accuracy of CNN model.

The evaluation of a model's accuracy often occurs subsequent to the estimation of its parameters and is quantified as a percentage. The accuracy of a model's predictions is determined by its ability to closely align with the actual data. Fig. 5Accuracy of CNN model. clarifies the accuracy of the CNN model, which reached above 98.59% in feature extraction with batch size = 64 and number of epochs = 40.

Confusion matrix:A confusion matrix is a tabular representation that provides a concise summary of the predictive performance of an ML model when evaluated against a specific set of test data. Measurement of classification model performance
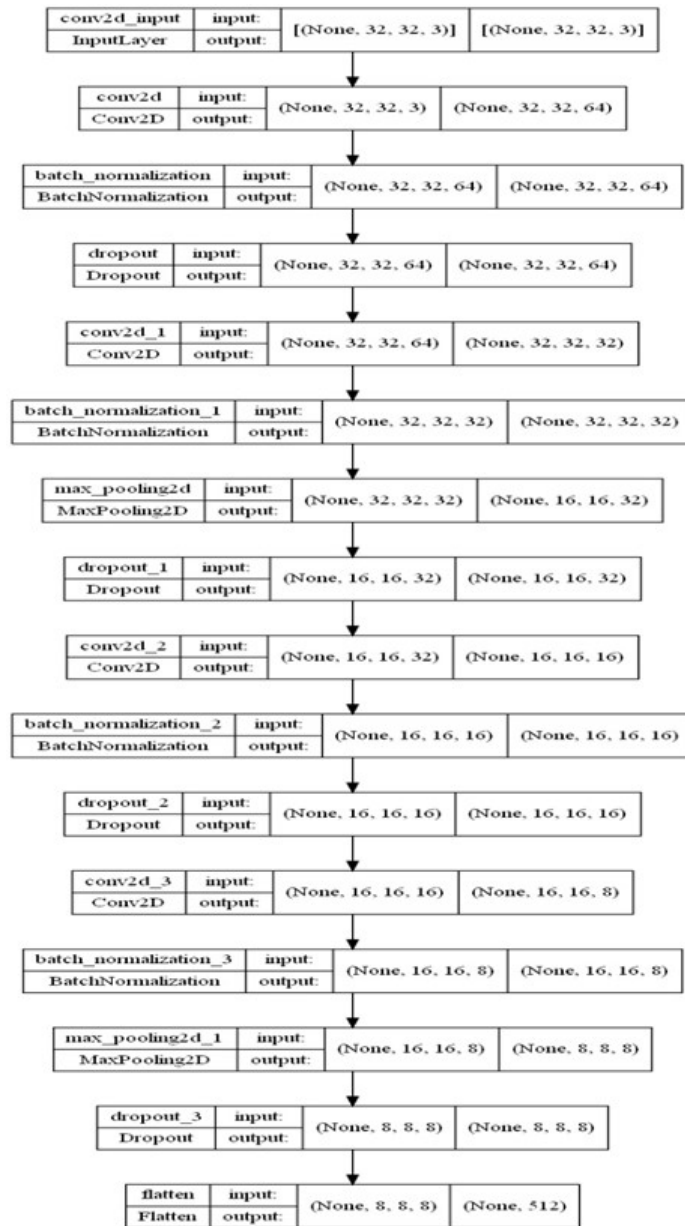
Fig. 3. CNN layers.

is frequently employed to assess the accuracy of predicting categorical labels for input instances. This provides a means of comparing the observed values with the values that were forecasted or estimated. The confusion matrix of the CNN model is shown in Fig. 6CNN confusion matrix. and 7CNN report of confusion matrix., where 0 denotes normal, 1 point denotes corrected, and 2 points denote reversal. This matrix is particularly useful for measuring important metrics: recall, precision, specificity, and accuracy. The elements within the matrix are classified as true positives (TP), true negatives (TN), false positives (FP), and false negatives (FN). A TP occurs when an observation is classified as positive and is correctly expected to be positive. An FN occurs when an observation is determined to be positive but is incorrectly anticipated to be negative. A TN occurs when the observed outcome is negative and is accurately anticipated to be negative. An FP

occurs when an observation is determined to be negative but is incorrectly anticipated to be positive.

$$
\begin{aligned}
\text{Accuracy} &= \frac{TP + TN}{TP + TN + FP + FN} \\
\text{Precision} &= \frac{TP}{TP + FP} \\
\text{Recall} &= \frac{TP}{TP + FN} \\
\text{F1-Score} &= \frac{2 * \text{precision} * \text{recall}}{\text{precision} + \text{Recall}}
\end{aligned}
\tag{2}
$$
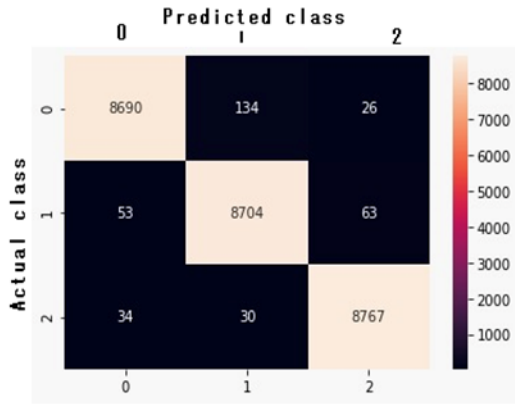
Fig. 6. CNN confusion matrix.
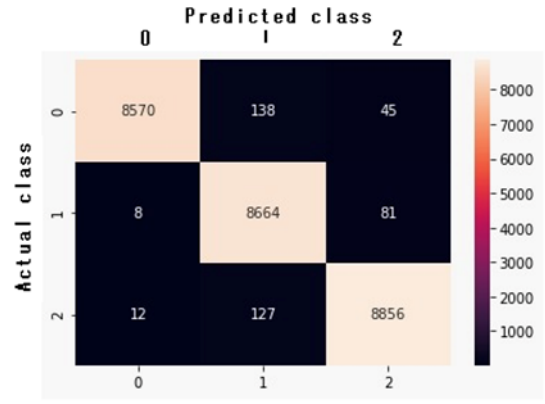


Fig. 9. CNN-RF confusion matrix.

The CNN-SVM model achieved high accuracy—99.33%—as illustrated in Fig. 10CNN-SVM report of confusion matrix. and 11CNN-SVM confusion matrix.. This proves what noted in [21]–[24] that SVM classifiers have a strong generalization ability.



|  | precision | recall | f1-score | support |
|---|---|---|---|---|
| Corrected | 0.99 | 0.98 | 0.99 | 8850 |
| Normal | 0.98 | 0.99 | 0.98 | 8820 |
| Reversal | 0.99 | 0.99 | 0.99 | 8831 |
| accuracy |  |  | 0.99 | 26501 |
| macro avg | 0.99 | 0.99 | 0.99 | 26501 |
| weighted avg | 0.99 | 0.99 | 0.99 | 26501 |

Fig. 7. CNN report of confusion matrix.



|  | precision | recall | f1-score | support |
|---|---|---|---|---|
| Corrected | 1.00 | 0.99 | 1.00 | 8753 |
| Normal | 0.99 | 0.99 | 0.99 | 8753 |
| Reversal | 0.99 | 0.99 | 0.99 | 8995 |
| accuracy |  |  | 0.99 | 26501 |
| macro avg | 0.99 | 0.99 | 0.99 | 26501 |
| weighted avg | 0.99 | 0.99 | 0.99 | 26501 |

Fig. 10. CNN-SVM report of confusion matrix.

In the CNN-RF model, the accuracy as we see in Fig. 8CNN-RF report of confusion matrix. and Fig. 9CNN-RF confusion matrix. achieved 98.44%



Fig. 11. CNN-SVM confusion matrix.



|  | precision | recall | f1-score | support |
|---|---|---|---|---|
| Corrected | 1.00 | 0.98 | 0.99 | 8753 |
| Normal | 0.97 | 0.99 | 0.98 | 8753 |
| Reversal | 0.99 | 0.98 | 0.99 | 8995 |
| accuracy |  |  | 0.98 | 26501 |
| macro avg | 0.98 | 0.98 | 0.98 | 26501 |
| weighted avg | 0.98 | 0.98 | 0.98 | 26501 |
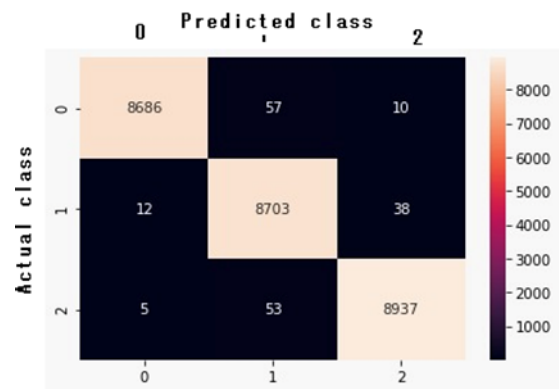
Fig. 8. CNN-RF report of confusion matrix.

*Comparison*: Comparison of the Proposed models with the models in previous studies on the same dataset demonstrated in Table IIComparison of the Proposed Models with Previous Studies Models which demonstrate the superiority of our study models.

TABLE II. COMPARISON OF THE PROPOSED MODELS WITH PREVIOUS STUDIES MODELS

| Models | Accuracy |
|---|---|
| LeNet-5 | 0.8873 |
| Modified LeNet-5 | 0.9534 |
| CNN | 0.9859 |
| CNN-RF | 0.9844 |
| CNN-SVM | 0.9933 |

## VII. CONCLUSION

In the field of image identification, the DL architecture known as CNN is becoming remarkably more significant. It has been utilized in all previous studies to recognize dyslexia through handwriting. Its performance has varied, starting at 55% and going up to 95% accuracy. This has been due to factors such as the small-scale size of the data set as well as problems with imbalanced classes. Our paper targeted developing the CNN model to maximize the performance in feature extraction and therefore classification and leveraging the combination of the DL and ML models to improve the prediction of dyslexia through handwriting image models, in terms of loss and accuracy, in the training model test. CNN-SVM outperformed CNN and CNN-RF, which reached 98.59% and 98.44%, respectively, while CNN-SVM achieved 99.33% in multiclass classification. Expanding research and the development of applications based on the identification of dyslexia through online handwriting is possible with the development of DL. We encourage researchers to seek to build a handwriting data set for children with dyslexia, as there is no collection currently available, except for those to whom the research has been applied.

## REFERENCES

[1] M. S. A. B. Rosli, I. S. Isa, S. A. Ramlan, S. N. Sulaiman, and M. I. F. Maruzuki, "Development of cnn transfer learning for dyslexia handwriting recognition," in *2021 11th IEEE Int. Conf. Control Syst. Comput. Eng. ICCSCE 2021*, 2021, pp. 194–199.

[2] Y. S. Kim, R. K. Wagner, and D. Lopez, "Developmental relations between reading fluency and reading comprehension: A longitudinal study from grade 1 to grade 2," *Journal of Experimental Child Psychology*, vol. 113, no. 1, pp. 93–111, 2012. [Online]. Available: http://dx.doi.org/10.1016/j.jecp.2012.03.002

[3] K. Spoon, D. Crandall, and K. Siek, "Towards detecting dyslexia in children's handwriting using neural networks," in *Int. Conf. Mach. Learn. AI Soc. Good Work.*, 2019, pp. 1–5.

[4] G. H. Kwak, C. W. Park, K. D. Lee, S. I. Na, H. Y. Ahn, and N. W. Park, "Potential of hybrid cnn-rf model for early crop mapping with limited input data," *Remote Sensing*, vol. 13, no. 9, 2021.

[5] N. D. Alqahtani, B. Alzahrani, and M. S. Ramzan, "Deep learning applications for dyslexia prediction," *Appl. Sci.*, vol. 13, no. 5, pp. 1–17, 2023.

[6] K. Spoon, K. Siek, D. Crandall, and M. Fillmore, "Can we (and should we) use ai to detect dyslexia in children's handwriting?" in *Artif. Intell. Soc. Good (NeurIPS 2019)*, 2019, pp. 1–6.

[7] I. S. Isa, W. N. S. Rahimi, S. A. Ramlan, and S. N. Sulaiman, "Automated detection of dyslexia symptom based on handwriting image for primary school children," *Procedia Comput. Sci.*, vol. 163, pp. 440–449, 2019.

[8] P. Yogarajah and B. Bhushan, "Deep learning approach to automated detection of dyslexia-dysgraphia," in *The 25th IEEE International Conference on Pattern Recognition*, 2020, pp. 1–12. [Online]. Available: https://www.micc.unifi.it/icpr2020/

[9] I. S. Isa, M. A. Zahir, S. A. Ramlan, W. Li-Chih, and S. N. Sulaiman, "Cnn comparisons models on dyslexia handwriting classification," *ES-TEEM Acad. J.*, vol. 17, no. March, pp. 12–25, 2021.

[10] H. Derrouz, A. Cabri, H. Ait Abdelali, R. Oulad Haj Thami, F. Bourzeix, S. Rovetta, and F. Masulli, "End-to-end quantum-inspired method for vehicle classification based on video stream," *Neural Computing and Applications*, vol. 34, no. 7, pp. 5561–5576, 2022.

[11] N. Altwaijry and I. Al-Turaiki, "Arabic handwriting recognition system using convolutional neural network," *Neural Comput. Appl.*, vol. 33, no. 7, pp. 2249–2261, 2021.

[12] W. Yang, D. Dai, B. Triggs, and G. S. Xia, "Sar-based terrain classification using weakly supervised hierarchical markov aspect models," *IEEE Trans. Image Process.*, vol. 21, no. 9, pp. 4232–4243, 2012.

[13] E. Othman, Y. Bazi, N. Alajlan, H. Alhichri, and F. Melgani, "Using convolutional features and a sparse autoencoder for land-use scene classification," *Int. J. Remote Sens.*, vol. 37, no. 10, pp. 2149–2167, 2016.

[14] C. K. Dewa, A. L. Fadhilah, and A. Afiahayati, "Convolutional neural networks for handwritten javanese character recognition," *IJCCS (Indonesian J. Comput. Cybern. Syst.*, vol. 12, no. 1, p. 83, 2018.

[15] S. Joseph and J. George, "Handwritten character recognition of modi script using convolutional neural network based feature extraction method and support vector machine classifier," in *2020 IEEE 5th Int. Conf. Signal Image Process. ICSIP 2020*, 2020, pp. 32–36.

[16] L. Chen, S. Wang, W. Fan, J. Sun, and N. Satoshi, "Reconstruction combined training for convolutional neural networks on character recognition," in *Proc. Int. Conf. Doc. Anal. Recognition, ICDAR*, vol. 2015-Novem, 2015, pp. 431–435.

[17] D. Decoste and B. Schölkopf, "Training invariant support vector machines," *Mach. Learn.*, vol. 46, no. 1–3, pp. 161–190, 2002.

[18] M. Z. Tsegaye and P. M. Shashi, "A new hybrid cnn-svm model for amharic character image recognition," vol. 9, no. 10, pp. 397–413, 2021.

[19] M. Elleuch, N. Tagougui, and M. Kherallah, "A novel architecture of cnn based on svm classifier for recognising arabic handwritten script," *Int. J. Intell. Syst. Technol. Appl.*, vol. 15, no. 4, pp. 323–340, 2016.

[20] A. A. A. Ali and S. Mallaiah, "Intelligent handwritten recognition using hybrid cnn architectures based-svm classifier with dropout," *J. King Saud Univ. - Comput. Inf. Sci.*, vol. 34, no. 6, pp. 3294–3300, 2022.

[21] H. Wu, D. Li, and M. Cheng, "Chinese text classification based on character-level cnn and svm," *Int. J. Intell. Inf. Database Syst.*, vol. 12, no. 3, pp. 212–228, 2019.

[22] S. S. Rosyda and M. I. Fanany, "Handwriting recognition on form document using convolutional neural network and support vector machines (cnn-svm)," in *2017 5th Int. Conf. Inf. Commun. Technol. ICoIC7 2017*, 2017.

[23] M. H. Momade, S. Shahid, M. R. bin Hainin, M. S. Nashwan, and A. Tahir Umar, "Modelling labour productivity using svm and rf: a comparative study on classifiers performance," *International Journal of Construction Management*, vol. 22, no. 10, pp. 1924–1934, 2022.

[24] V. F. Rodriguez-Galiano, B. G. B, J. Rogan, M. Chica-Olmo, and J. P. Rigol-Sanchez, "An assessment of the effectiveness of a random forest classifier for land-cover classification," *ISPRS J. Photogramm. Remote Sens.*, vol. 67, pp. 93–104, 2012. [Online]. Available: https://doi.org/10.1016/j.isprsjprs.2011.11.002

[25] L. Breiman, "Random forests," *Mach. Learn.*, vol. 45, no. 1, pp. 5–32, 2001.

[26] S. Barton, "How to spot dyslexia in a writing sample," 2017.

[27] Dyslexia handwriting dataset. Kaggle. Accessed on Sep. 10, 2023. [Online]. Available: https://www.kaggle.com/datasets/drizasazanitaisa/dyslexia-handwriting-dataset

[28] Nist special database 19. NIST. Accessed on Nov. 04, 2022. [Online]. Available: https://www.nist.gov/srd/nist-special-database-19

[29] A-z handwritten alphabets in .csv format. Kaggle. Accessed on Nov. 04, 2022. [Online]. Available: https://www.kaggle.com/datasets/sachinpatel21/az-handwritten-alphabets-in-csv-format

[30] M. A. H. Akhand, M. Ahmed, M. M. H. Rahman, and M. M. Islam, "Convolutional neural network training incorporating rotation-based generated patterns and handwritten numeral recognition of major indian scripts," *IJETE J. Res.*, vol. 64, no. 2, pp. 176–194, 2018.

[31] S. S. Rosyda and T. W. Purboyo, "A review of various handwriting recognition methods," *Int. J. Appl. Eng. Res.*, vol. 13, no. 2, pp. 1155–1164, 2018.

[32] J. Koushik, "Understanding convolutional neural networks using a minimal model for handwritten digit recognition," arXiv preprint, 2016. [Online]. Available: http://arxiv.org/abs/1605.09081

[33] J. Bjorck, C. Gomes, B. Selman, and K. Q. Weinberger, "Understanding batch normalization," *arXiv preprint*, vol. 4, no. NeurIPS, pp. 1–24, 2018.

[34] P. Wang, E. Fan, and P. Wang, "Comparative analysis of image classification algorithms based on traditional machine learning and deep learning," *Pattern Recognition Letters*, vol. 141, pp. 61–67, 2021.

[35] J. Bjorck, C. Gomes, B. Selman, and K. Q. Weinberger, "Understanding batch normalization," *arXiv preprint*, vol. 4, no. NeurIPS, pp. 1–24, 2018.

[36] P. Wang, E. Fan, and P. Wang, "Comparative analysis of image classification algorithms based on traditional machine learning and deep learning," *Pattern Recognition Letters*, vol. 141, pp. 61–67, 2021.

# A Hybrid Meta-heuristic Algorithm for Edge Site Deployment with User Coverage Maximization and Cost Minimization

Xiaodong Xing[1],Ying Song[2], Bo Wang[3]

School of Computer and Network Engineering, Shanxi Datong University, Shanxi, China 037009[1]

Computer School, Beijing Information Science and Technology University, Beijing, China 100192[2]

Software Engineering College, Zhengzhou University of Light Industry, Zhengzhou, China 450001[3]

*Abstract*—Recent years, edge computing has been getting increased attention due to its ultra-low delay service deliveries. Plenty of works have focused on the performance improvement of edge computing by e.g., edge server deployment, edge caching, and task offloading. While, there is a lack of work on improving the investment cost for building or upgrading the edge site deployment by making a decision on which places edge sites are deployed. In this paper, we focus on the edge site deployment problem (ESDP) to maximize user coverage with fewest edge sites. We first formulate ESDP into a binary nonlinear programming with two optimization objectives of user coverage maximization and edge site minimization, and prove that ESDP is NP-complete. Then, we propose a hybrid meta-heuristic algorithm to solve ESDP with polynomial time complexity, which combining the crossover and mutation operators of genetic algorithm with self- and social-cognition of particle swarm optimization. At last, we conduct extensive simulated experiment based on a real data set to evaluate the performance of our proposed algorithm. The results show that our algorithm achieves 100% user coverage with much fewer edge sites than other seven meta-heuristic algorithms, and has a good scalability.

*Keywords*—*Edge computing; edge deployment; GA; PSO; meta-heuristic*

## I. INTRODUCTION

Over the past two decades, cloud computing has been applied in all fields, due to its numerous benefits, e.g., on-demand, flexibility, reliability [1]. But in recent years, cloud computing alone cannot satisfy real time requirements of many user requests [2], especially in mobile networks. This is mainly because cloud resources are shared by users around the world and cloud computing platforms provide services over Wide Area Networks (WAN) that generally have high latencies. In addition, more and more users request services by mobile devices nowadays [3] with the rapid development of communication and network technologies, which results in a highly dynamic locations where requests are initiated and thus a much fluctuating communication performance between users and cloud computing platforms.

Therefore, in recent years, edge computing is becoming more and more popular in both industry and academia, because it can efficiently compensate for the shortcomings of cloud computing [4], [5]. In edge computing, some computing and storage resources are deployed close to user devices, and thus ultra-low latency services can be provided for users. While, due to the distribution and heterogeneity of limited edge resources,

it is a very challenging work to provide high quality services for all users. Many works have focused on addressing the challenge in various aspects including edge server placement [6], [7], edge caching [8], [9], task offloading [10], [11] and so on. While, all of works assume that edge sites have been deployed, where edge resources are placed and used for processing requests. For each request, it can be accepted by closely located edge sites, because edge sites provide Local Area Network (LAN) connections for users usually by wireless networks in a short distance. Thus, the locations of edge sites have an effect on the service quality, by deciding which edge resources can be used for processing every request. Therefore, in this paper, we focus on the edge site deployment problem (ESDP) that is deciding which of multiple candidate places to be edge sites.

For a user, if it is not covered by the network signal of any edge site, then it cannot communicate with any edge site. In such case, the user's requests cannot received by an edge site, and thus cannot be processed by edge resources, which can cause major performance degradation of these requests. Therefore, in this paper, we identify maximizing user coverage as a major objective, which is maximizing the number of users that are covered by the network signal of at least one edge site. As the profit maximization is the first aim of service providers, in this paper, we consider the deployment cost as the second optimization objective by minimizing the number of deployed edge site.

Due to geographical characteristics and urban planning, candidate places generally are dispersive. This leads to that ESDP is a discrete optimization problem and hard to be solved precisely. Therefore, in this paper, we exploit meta-heuristic algorithms for solving ESDP, due to their powerful search ability [12]. To be specific, we consider to exploit Genetic Algorithm (GA) and Particle Swarm Optimization (PSO), which are most representative evolutionary algorithm and swarm intelligence, respectively. GA, inspired by Darwin's theory of evolution, has powerful global search ability by evolutionary operators but usually convergences slowly [13]. PSO is designed based on the movements of birds for foraging, which has high convergence speed but is easily trapping into local best positions [14]. Thus, GA and PSO are complement each other, and we design a hybrid meta-heuristic algorithm by combining their advantages for providing a ESDP solution with maximized user coverage and minimized monetary cost. In brief, the contributions of this paper are as followings.

- First, ESDP is formulated as a binary non-linear programming, and its hardness is proven. The objectives include the user coverage maximization and the monetary cost minimization.

- Then, a hybrid meta-heuristic algorithm is proposed for solve ESDP in polynomial time complexity by combining GA and PSO. The hybrid algorithm uses the swarm evolving framework of PSO to exploit the self- and social-cognitions, and employs the mutation and crossover operators of GA to ensure the population diversity for a powerful global search ability.

- At last, the performance of proposed algorithm is evaluated by extensive simulated experiments that are designed based on a real data set. Experiment results show that the proposed algorithm achieves 100% user coverage and requires much less edge sites than several other meta-heuristic and hybrid algorithms.

The rest of this paper is organized as followings. Section II presents the formulation of ESDP. Section III illustrates the proposed meta-heuristic algorithm, and section IV shows the performance evaluation results. Section V discusses the related works. At last, Section VI concludes this work.

## II. PROBLEM STATEMENT

In this paper, we consider to select part of multiple candidate places to deploy edge sites for providing edge computing services. Assuming that there are $P$ candidate places represented as $p_i, 1 \leq i \leq P$. For candidate place $p_i$, its location is $(l_{i,1}^P, l_{i,2}^P)$, which can be either latitude and longitude in geographic coordinate or horizontal and vertical values in Cartesian coordinate. When an edge site is decided to be deployed on $p_i$, there will be $m_i$ monetary cost. For each edge site, the maximal distance of network signal is $S$. This is meaning that a user is covered by an edge site or a candidate place if and only if their distance is smaller than $S$. The edge site deployment decisions can be indicated by binary variables $x_i, 1 \leq i \leq P$, where $x_i = 1$ means $p_i$ is selected for deploying an edge site, and $x_i = 0$ means not. In this case, the total monetary cost $C$ can be calculated by Eq. (1).

$$C = \sum_{i=1}^{P}(m_i x_i) \qquad (1)$$

In the considered edge computing, there are $U$ users $(u_j, 1 \leq i \leq U)$. The location of $u_j$ is $(l_{j,1}^U, l_{j,2}^U)$. Then, the distance $(d)$ between users and candidate places can be calculated by Eq. (2) and (3), respectively, when using geographic and Cartesian coordinate systems. Where $R$ is the earth radius, which is usually set as 6371.393 kilometres.

$$\begin{aligned} d_{i,j} = \ & R \arccos(\cos l_{i,1}^U \cos l_{j,1}^P \cos(l_{i,2}^P - l_{j,2}^U) \\ & + \sin l_{i,1}^P \sin l_{j,1}^U) \end{aligned} \qquad (2)$$

$$d_{i,j} = \sqrt{(l_{i,1}^P - l_{j,1}^U)^2 + (l_{i,2}^P - l_{j,2}^U)^2} \qquad (3)$$

Then, the cover between users and candidate places can be achieved by Eq. (4), where $c_{i,j} = 1$ represents $u_j$ is covered by $p_i$, and $u_j$ can be served by the edge site deployed on $p_i$ during

the operation of edge computing. And, we can get the set of covered users for each candidate places, $\mathbb{C}_i = \{u_j | c_{i,j} = 1\}$, and the set of all covered tasks by selected candidate places, $\mathbb{C} = \cup_{x_i=1} \mathbb{C}_i$. Now, we can calculate the overall user coverage by Eq. (5).

$$c_{i,j} = \begin{cases} 1, & \text{if } d_{i,j} \leq S \\ 0, & \text{if } d_{i,j} > S \end{cases} \qquad (4)$$

$$Q = \frac{|\mathbb{C}|}{U} \times 100\% \qquad (5)$$

Based on above formulations, we can now model ESDP as following optimization problem. The two objectives are maximizing the user coverage (Eq. (6)) and minimizing the cost of deployed edge sites (Eq. (7)), respectively. Decision variables include $x_i, 1 \leq i \leq P$, which are all binary. As the nonlinear of Eq. (5), the ESDP is a binary nonlinear programming.

$$\text{maximizing} \quad Q, \qquad (6)$$
$$\text{minimizing} \quad C. \qquad (7)$$

In this paper, we consider coverage maximization as the major objective. Then, the two objectives Eq. (6) and Eq. (7) can be convert into one, as shown in Eq. (8). $UQ = |\mathcal{C}|$ is the number of covered users. $\sum_{i=1}^{P} m_i$ is the total cost when all candidate places are selected for deploying edge sites, which is greater than or equal to $C$, and thus $\frac{C}{\sum_{i=1}^{P} m_i} \leq 1$.

$$\text{maximizing } O = UQ - \frac{C}{\sum_{i=1}^{P} m_i} \qquad (8)$$

Next, we proof that ESDP is NP-Complete, which means no polynomial algorithm can exactly solve it unless P=NP, and in the next section, we will present a hybrid meta-heuristic algorithm to solving it in a polynomial algorithm with global search abilities of GA and PSO. Considering an instance of ESDP, all user can be covered and costs of edge site deployments on all candidate places are identical. Then, the ESDP instance is to minimize the number of deployed edge sites with 100% user coverage, which can be formulated following optimization problem. Objective (9) is minimizing the number of selected candidate places for deploying edge sites. Constraints (11) require that every user must be covered by at least one selected candidate place or deployed edge site. Constraints (11) represent that decision variables are binary. Therefore, the ESDP instance is binary linear programming which has been proven as NP-complete [15]. Thus, ESDP is NP-complete.

$$\text{minimizing } \sum_{i=1}^{P} x_i, \qquad (9)$$

subject to,

$$\sum_{i=1}^{P} c_{i,j} x_i \geq 1, 1 \leq j \leq U, \qquad (10)$$

$$x_i \in \{0,1\}, 1 \leq i \leq P. \qquad (11)$$

## III. Hybrid GA and PSO for Edge Site Deployment

In this section, we propose a hybrid meta-heuristic algorithm aiming to search a global best solution for ESDP. In this paper, we choose to employ GA and PSO, and will exploit other meta-heuristics for more powerful global search ability and efficiency. The reasons of choosing GA and PSO are two-fold. One is that both GA and PSO are most representative meta-heuristic algorithms and have widely used in various fields due to their good performance and easily implementations [14], [16]. Another is that one's advantage can make up another's disadvantage for GA and PSO, as GA has powerful global search ability but slow convergence speed, and on the contrary, PSO has fast convergence speed but is easily trapping into local optima. Fig. 1 gives the flow chart of our proposed hybrid meta-heuristic algorithm for ESDP, which is represented by PGSAO.
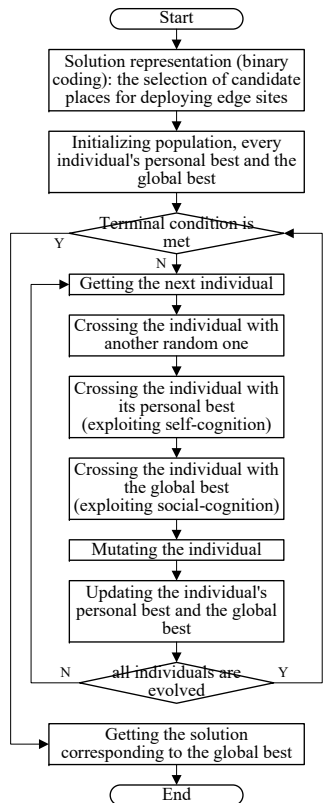


Fig. 1. The algorithm flow chart of the hybrid GA and PSO for edge site deployment.

As shown in Fig. 1, at first, PGSAO employs a binary coding method to establish the solution space for meta-heuristic algorithms' searching. A solution of ESDP is represented as a $P$-dimensional vector, $\langle x_1, x_2, ..., x_P \rangle$, where values in all dimensions are binary, indicating whether edge sites are deployed on the corresponding places. During the search, there is a fitness function used for evaluating the goodness for each individual/solution. In this paper, we identify user coverage maximization as the major objective and deployed edge site number as the minor objective. Thus, the fitness function of

PGSAO is defined as Eq. (12).

$$f = |\mathbb{C}| + \frac{\sum_{i=1}^{P} x_i}{P}. \tag{12}$$

Given the solution space and the fitness function, PGSAO first initializes a population consisting of multiple individuals (chromosomes, particles), where every individual is a solution, by randomly setting a value on each dimension of every individual. Then, for each individual, PGSAO evaluates its fitness, and records itself as its personal best. After the fitness evaluation, PGSAO finds the individual with the highest fitness, and records it as the global best. Now, PGSAO proceeds to the evolutionary stage to upgrade individuals for retrieving better or even global best solutions.

In the evolutionary stage, PGSAO repeats upgrading the population by performing crossover and mutation operators on every individual as following steps until the terminal condition is met. (1) The individual is crossed with another one that is selected randomly with the crossover probability, which is same to GA. (2) The individual is crossed with its personal best with the crossover probability, which is exploiting the self-cognition of PSO. (3) The individual is crossed with the global best with the crossover probability for employing the social-cognition of PSO. (4) The individual is mutated with the mutation probability, as done by GA for increasing the population diversity. (5) For each individual, by three crossover operators (steps 1, 2, and 3) and one mutation operator (step 4), total seven offspring are produced (two for a crossover and one for a mutation). At the end of each individual's evolution, its personal best and global best are updated as the best offspring when an offspring has better fitness.

In this paper, to ensure the population diversity, PGSAO employs the uniform crossover and the uniform mutation operators. The uniform crossover operator is to swap the values on every dimension of two individuals with a probability, which represents exchanging the selection states of a candidate place between two solutions. By the uniform mutation operator for an individual, each dimension is changed from one value (0/1) to another one (1/0) with a probability, which represents changing the selections of candidate places on the solution.

PGSAO is terminated when the repeat time reaches the predefined threshold or there is no change on the global best a few times continuously. And PGSAO returns the solution corresponding to the global best.

## IV. Performance Evaluation

To evaluate the performance of PGSAO, we conduct extensive simulated experiments based on a real data set, EUA [17], [18], which includes locations of 9318 LTE base station sites and 131312 users in the Melbourne CBD area. We consider LTE base station sites as candidate places in ESDP. In our experiment, we convert the geographic coordinate into a Cartesian coordinate system by setting one degree as 1000 metres in both longitude and latitude for just simplifying the calculation of distances, and set the coverage of each edge site as 100 metres referring to existing related works.

The performance metrics used for evaluating PGSAO include the user coverage and the number of selected candidate

places for edge site deployment. For the first metric, it is better for a greater value, and 100% is the best value. For the second one, a smaller number is better, which indicates a lower cost for edge site deployment.

To prove the superiority of our method, we compare PGSAO with five classical and widely used meta-heuristic algorithms, GA [16], Differential Evolution (DE) [19], Artificial Bee Colony (ABC) [20], PSO [14] and Multi-Verse Optimizer (MVO) [21], and two hybrid meta-heuristic algorithms (GAPSO [22] and PSOGA) in solving ESDP. GAPSO is to perform GA in the first half of the evolutionary stage, and PSO in the second half. PSOGA reverses the order of GA and PSO for GAPSO.

### A. Overall Performance

For each experiment, we repeat eight times and show results by the box-plot. In our experiment, all algorithms achieve 100% user coverage, which verifies the powerful search ability of meta-heuristics. In Fig. 2, we present the number of deployed edge sites when applying various algorithms. From the figure, we can see that PGSAO requires the fewest edge sites for full user coverage, and thus the minimal deployment cost. On average, PGSAO requires to deploy 16.0%–31.7% fewer edge sites than other methods. This verifies that the performance superiority of PGSAO in the global optimization, compared with other [hybrid] meta-heuristic algorithms. This is mainly because of the efficient fusion of GA and PSO in the following two aspects. First, hybrid meta-heuristic algorithms, GAPSO, PSOGA, and PGSAO, achieve better performance than single meta-heuristic algorithms, GA, DE, ABC, PSO, and MVO, in minimizing the number of deployed edge sites, which verifies the validity of combining different meta-heuristic algorithms for a better performance. Second, PGSAO needs fewer deployed edge sites than GAPSO and PSOGA. This proves that the high efficiency of the combination strategy exploited by PGSAO, as GAPSO, PSOGA, and PGSAO are all combining GA and PSO.
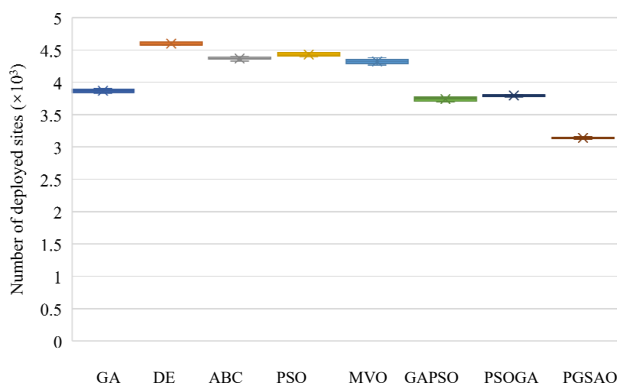


Fig. 2. The number of deployed edge sites for user coverage maximization when applying various algorithms.

We also perform t-test to verify the statistical difference of our method to others in optimizing deployed edge site number, and present the test results in Table I. As shown in the table, the $p$-values of all t-test are much smaller than 0.01. Thus, PGSAO has significantly different performance to other algorithms, which confirms the superiority of PGSAO further.

TABLE I. $p$-VALUES OF T-TEST ON THE STATISTICAL EQUALITY OF PGSAO TO OTHER ALGORITHMS

| Method | $p$-value |
|--------|-----------|
| GA | $1.33 \times 10^{-15}$ |
| DE | $2.60 \times 10^{-20}$ |
| ABC | $3.41 \times 10^{-20}$ |
| PSO | $9.72 \times 10^{-19}$ |
| MVO | $3.89 \times 10^{-14}$ |
| GAPSO | $1.32 \times 10^{-12}$ |
| PSOGA | $7.94 \times 10^{-21}$ |

In the next, we compare the time consumed by various algorithms, where the results are shown in Fig. 3. The time is tested on a personal computer with Window 11, Intel(R) Core(TM) i7-4770 CPU @ 3.40GHz, and 24 GiB RAM. As shown in the figure, PGSAO consumes about five times time of others, where the increased time is mainly consumed for exploiting self- and social cognitions by crossover operators of PGSAO. Even so, it is absolutely a worthwhile trade-off for a much lower deployment cost, noticing the following observation. The edge deployment strategy is stable. There are mainly two cases in which service providers need edge deployment solutions, building or upgrading edge computing on some new or original areas when providers decide to develop new business or user traffics are increased greatly. For both cases, it generally takes a long time, e.g., months or years, for changing the edge deployment solution. Thus, service providers prefer to consume more hours for an edge deployment solution with much lower cost.
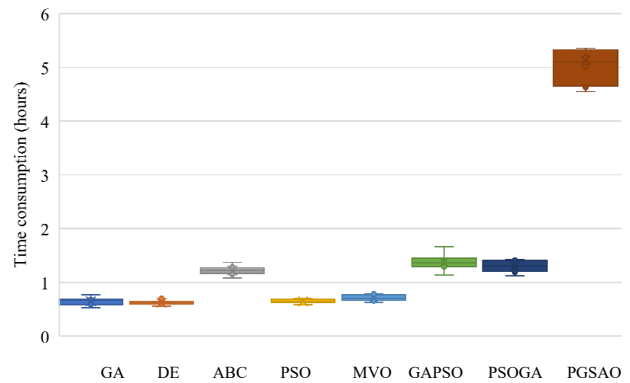


Fig. 3. The time consumed by different algorithms.

### B. Performance Varied with User Number

Now, we exam the performance variations with the user number for different algorithms. Fig. 4 and 5 give such variations when the user number is changed from 10,000 to 100,000. The user coverage is always 100% for every algorithm in any case. As shown in Fig. 4, we can see that the number of required edge site for the full user coverage is stable with varied user number for every algorithm. This is mainly because the area size instead of the user number determine the number of required edge site for a full coverage, given the fixed coverage range of each edge site. From Fig. 4, PGSAO always requires minimal number of edge sites than others, and thus has the best performance in minimizing the deployment cost.

As shown in Fig. 5, we can see that every algorithm consumes time increased linearly with the increase of the user number in overall. This is mainly because all users are traversed once for calculating the fitness for each individual. This verifies that all algorithms including ours have good scalability in solving various scale ESDP, and thus have good usability.
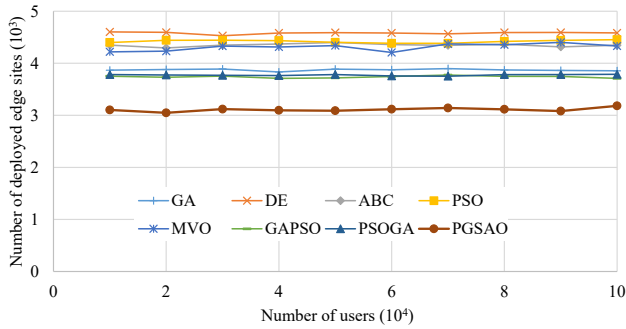


Fig. 4. The number of deployed edge sites required by various algorithms with varied user numbers.
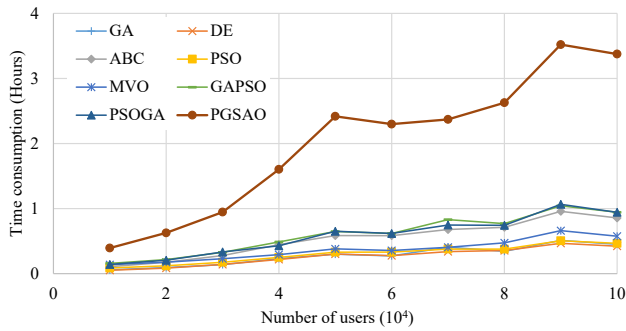


Fig. 5. The time consumed by different algorithms with varied user numbers.

### C. Performance Varied with Candidate Site Number

We also evaluate the performance variations with the candidate place number for each algorithm on solving ESDP, and present results in Fig. 6 and 7, where the number of candidate places is in the range from 1000 to 9000. Same to previous results, all algorithms can achieve 100% user coverage, confirming the effectiveness of their search strategies. From Fig. 6, we can see that as the number of candidate places increases, more edge sites are required for deployment for every algorithm, i.e., the performance is degraded. This is mainly because as the number of candidate places increases, the search space is exponentially increased, and thus it is more and more difficult to retrieve the global best solution.

As shown in Fig. 7, the consumed time is stable as the number of candidate places is varied for every algorithm, as the main time overhead is consumed for the population evolution and thus mainly decided by population size and iteration number. This phenomenon further confirms the good scalability of our algorithm.
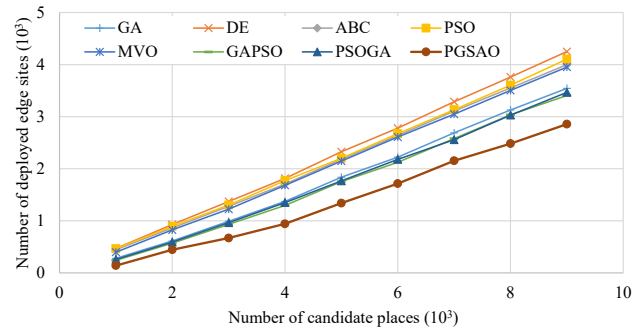


Fig. 6. The number of deployed edge sites required by various algorithms with varied candidate places.
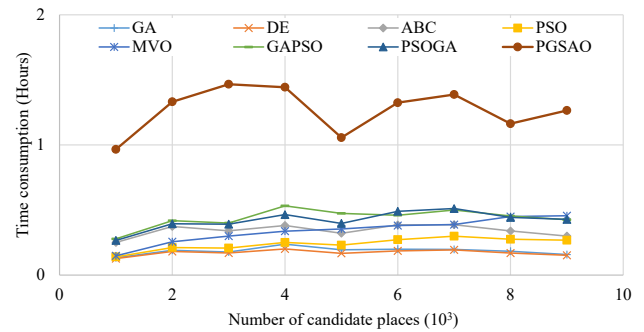


Fig. 7. The time consumption changed with varied number of candidate places for each algorithm.

## V. Related Works

Edge-cloud computing has attract more and more attention from both industry and academia due to its huge advantage by combing edge and cloud computing. Several works have aimed at designing edge server placement approaches, edge service/data caching strategies, and task offloading algorithms to improve the efficiency and effectiveness of edge-clouds, which are discussed as follows, respectively.

Given the edge site deployment solution, edge server placement is to decide which sites edge servers (resources) are placed to maximize the overall performance with restricted edge resources. Zhang et al. [23] proposed a niche PSO to minimize the overall respond time considering the placement as a multimodal optimization problem, which divides similar individuals into a niche during the population upgrade. Li et al. [24] and Zhang et al. [25] employed K-means++ to cluster edge sites into $k$ classes, and deploy $k$ edge servers on the sites closest to theses classes' centres. These works assumed that all edge sites have been deployed, and thus our work is complementary to them. These works only considered to improve request processing performance with fixed number of edge servers, without concerning the investment cost improvement for building edge computing platforms.

During operation of edge computing, as resources configured in each edge site are restricted, there is no enough room for storing all services or data requested by users in the edge. Therefore, an edge caching strategy decides which

service data that are deployed (cached) on every edge site for processing corresponding requests, and affect the performance by determining whether or not a request can be processed in edge servers. There mainly two kinds of edge caching, static and dynamic strategies. Static strategies provide a solution that the placement of services or data on edge sites is not changed, e.g., [26], [27], [28], while dynamic strategies adjust the placement over time, e.g., [29], [30], [31].

Another key work to tune the performance of operating edge computing is task offloading/scheduling that decides the resource that every request task is processed on. Laboni et al. [32] proposed a two-layer hyper heuristic algorithm to determinate the server and router path for each request's processing for optimizing processing delay and load balance. They exploited ant colony optimization as the high-level algorithm for selecting the low-level algorithm employed for each population evolution, and Whale optimization, sine-cosine algorithm as well as Henry gas solubility optimization as low-level algorithms. Zhang and Yu [33] proposed a hybrid task offloading algorithm by combining ABC and PSO, to improving processing delay and energy consumption. Concerned about service caching, Zhang et al. [34] formulated the task offloading problem into a mixed-integer non-linear programming, and exploited non-cooperative game to iteratively solving the problem by the interaction between wireless characteristics and mobile users. Both edge caching and task offloading are used for improving performance during the operation of edge computing, and thus requires that the edge sites and resources have been deployed. Therefore, our work focusing on ESDP is complement with these existing related works.

## VI. Conclusion

In this paper, we focus on the edge site deployment problem (ESDP) to improve the build/upgrade cost to provide ESDP solution for service providers to expand their businesses. To achieve this goal, we first formulate ESDP into a binary non-linear programming problem with two objectives, user coverage maximization and edge site number minimization. And we prove the NP-complete of ESDP by establishing an ESDP instance that is binary linear programming. Then, we propose a hybrid GA and PSO algorithm aiming to retrieve the global best solution of ESDP. The proposed algorithm combines the global search ability of GA and cognitions exploited by PSO, to achieve a more efficient search strategy. In the end, we evaluate the performance of our proposed algorithm based on a real data set, and confirm the superiority of our algorithm in various aspects.

## Acknowledgment

## References

[1] M. Armbrust, A. Fox, R. Griffith, A. D. Joseph, R. Katz, A. Konwinski, G. Lee, D. Patterson, A. Rabkin, I. Stoica, and M. Zaharia, "A view of cloud computing," *Communications of the ACM*, vol. 53, no. 4, p. 50–58, Apr 2010. [Online]. Available: https://doi.org/10.1145/1721654.1721672

[2] T. Wang, Y. Liang, X. Shen, X. Zheng, A. Mahmood, and Q. Z. Sheng, "Edge computing and sensor-cloud: Overview, solutions, and directions," *ACM Computing Surveys*, vol. 55, no. 13s, Jul 2023. [Online]. Available: https://doi.org/10.1145/3582270

[3] X. Wang, J. Li, Z. Ning, Q. Song, L. Guo, S. Guo, and M. S. Obaidat, "Wireless powered mobile edge computing networks: A survey," *ACM Comput. Surv.*, vol. 55, no. 13s, jul 2023. [Online]. Available: https://doi.org/10.1145/3579992

[4] S. Ahmad, I. Shakeel, S. Mehfuz, and J. Ahmad, "Deep learning models for cloud, edge, fog, and iot computing paradigms: Survey, recent advances, and future directions," *Computer Science Review*, vol. 49, p. 100568, 2023. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S1574013723000357

[5] B. Wang, C. Wang, W. Huang, Y. Song, and X. Qin, "A survey and taxonomy on task offloading for edge-cloud computing," *IEEE Access*, vol. 8, pp. 186 080–186 101, 2020.

[6] B. Bahrami, M. R. Khayyambashi, and S. Mirjalili, "Edge server placement problem in multi-access edge computing environment: models, techniques, and applications," *Cluster Computing*, vol. 26, no. 5, p. 3237–3262, 2023.

[7] S. Wang, Y. Zhao, J. Xu, J. Yuan, and C.-H. Hsu, "Edge server placement in mobile edge computing," *Journal of Parallel and Distributed Computing*, vol. 127, pp. 160–168, 2019. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0743731518304398

[8] J. Yao, T. Han, and N. Ansari, "On mobile edge caching," *IEEE Communications Surveys & Tutorials*, vol. 21, no. 3, pp. 2525–2553, 2019.

[9] M. Reiss-Mirzaei, M. Ghobaei-Arani, and L. Esmaeili, "A review on the edge caching mechanisms in the mobile edge computing: A social-aware perspective," *Internet of Things*, vol. 22, p. 100690, 2023. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S2542660523000136

[10] Y. Sang, J. Wei, Z. Zhang, and B. Wang, "A hybrid heuristic service caching and task offloading method for mobile edge computing," *Computers, Materials & Continua*, vol. 76, no. 2, pp. 2483–2502, 2023. [Online]. Available: http://www.techscience.com/cmc/v76n2/54015

[11] B. Wang, Z. Zhang, Y. Song, M. Chen, and Y. Chu, "Application of quantum particle swarm optimization for task scheduling in device-edge-cloud cooperative computing," *Engineering Applications of Artificial Intelligence*, vol. 126, p. 107020, 2023. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0952197623012046

[12] K. Hussain, M. N. M. Salleh, S. Cheng, and Y. Shi, "Metaheuristic research: a comprehensive survey," *Artificial Intelligence Review*, vol. 52, no. 4, p. 2191–2233, 2019.

[13] S. Mirjalili, "Genetic algorithm," *Evolutionary Algorithms and Neural Networks: Theory and Applications*, pp. 43–55, 2019. [Online]. Available: https://doi.org/10.1007/978-3-319-93025-1_4

[14] J. Nayak, H. Swapnarekha, B. Naik, G. Dhiman, and S. Vimal, "25 years of particle swarm optimization: Flourishing voyage of two decades," *Archives of Computational Methods in Engineering*, vol. 30, no. 3, p. 1663–1725, 2023.

[15] E. M. Gurari and O. H. Ibarra, "An np-complete number-theoretic problem," in *Proceedings of the Tenth Annual ACM Symposium on Theory of Computing*, ser. STOC '78. New York, NY, USA: Association for Computing Machinery, 1978, p. 205–215. [Online]. Available: https://doi.org/10.1145/800133.804349

[16] S. Katoch, S. S. Chauhan, and V. Kumar, "A review on genetic algorithm: past, present, and future," *Multimedia Tools and Applications*, vol. 80, no. 4, pp. 8091–8126, 2021.

[17] P. Lai, Q. He, M. Abdelrazek, F. Chen, J. Hosking, J. Grundy, and Y. Yang, "Optimal edge user allocation in edge computing with variable sized vector bin packing," in *16th International Conference on Service-Oriented Computing (ICSOC 2018)*, ser. ICSOC 2018, 2018, pp. 230–245. [Online]. Available: https://doi.org/10.1145/800133.804349

[18] Swin Edge, "EUA datasets: Edge server, user dataset for edge computing research," https://github.com/swinedge/eua-dataset, 2021.

[19] Bilal, M. Pant, H. Zaheer, L. Garcia-Hernandez, and A. Abraham, "Differential evolution: A review of more than two decades of research," *Engineering Applications of Artificial Intelligence*, vol. 90, p. 103479, 2020.

[20] K. Thirugnanasambandam, M. Rajeswari, D. Bhattacharyya, and J. yoon Kim, "Directed artificial bee colony algorithm with revamped search strategy to solve global numerical optimization problems," *Automated Software Engineering*, vol. 29, no. 13, pp. 1–31, 2022.

[21] S. Mirjalili, S. M. Mirjalili, and A. Hatamlou, "Multi-verse optimizer: a nature-inspired algorithm for global optimization," *Neural Computing and Applications*, vol. 27, no. 2, p. 495–513, 2016.

[22] H. Hafsi, H. Gharsellaoui, and S. Bouamama, "Genetically-modified multi-objective particle swarm optimization approach for high-performance computing workflow scheduling," *Applied Soft Computing*, vol. 122, p. 108791, 2022.

[23] X. Zhang, J. Zhang, C. Peng, and X. Wang, "Multimodal optimization of edge server placement considering system response time," *ACM Transactions on Sensor Networks*, vol. 19, no. 1, dec 2022. [Online]. Available: https://doi.org/10.1145/3534649

[24] W. Li, J. Chen, Y. Li, Z. Wen, J. Peng, and X. Wu, "Mobile edge server deployment towards task offloading in mobile edge computing: A clustering approach," *Mobile Networks and Applications*, vol. 27, no. 4, p. 1476–1489, Aug 2022.

[25] H. Zhang, J. Zhao, L. Yang, and Z. Zhang, "Mobile edge computing servers deployment with improved genetic algorithm in cellular internet of things," *China Communications (Early Access)*, 2023.

[26] J. Zhou, F. Chen, Q. He, X. Xia, R. Wang, and Y. Xiang, "Data caching optimization with fairness in mobile edge computing," *IEEE Transactions on Services Computing*, vol. 16, no. 3, pp. 1750–1762, 2023.

[27] S. Tang, K. He, L. Chen, L. Fan, X. Lei, and R. Q. Hu, "Collaborative cache-aided relaying networks: Performance evaluation and system optimization," *IEEE Journal on Selected Areas in Communications*, vol. 41, no. 3, pp. 706–719, 2023.

[28] X. Wei and Y. Wang, "Popularity-based data placement with load balancing in edge computing," *IEEE Transactions on Cloud Computing*, vol. 11, no. 1, pp. 397–411, 2023.

[29] C.-K. Huang and S.-H. Shen, "Enabling service cache in edge clouds," *ACM Transactions on Internet of Things*, vol. 2, no. 3, jul 2021. [Online]. Available: https://doi.org/10.1145/3456564

[30] T. Zong, C. Li, Y. Lei, G. Li, H. Cao, and Y. Liu, "Cocktail edge caching: Ride dynamic trends of content popularity with ensemble learning," *IEEE/ACM Transactions on Networking*, vol. 31, no. 1, p. 208–219, aug 2023. [Online]. Available: https://doi.org/10.1109/TNET.2022.3193680

[31] S. Zhou, Z. Wang, C. Hu, Y. Mao, H. Yan, S. Zhang, C. Wu, and W. Zhu, "Caching in dynamic environments: A near-optimal online learning approach," *IEEE Transactions on Multimedia*, vol. 25, pp. 792–804, 2023.

[32] N. M. Laboni, S. J. Safa, S. Sharmin, M. A. Razzaque, M. M. Rahman, and M. M. Hassan, "A hyper heuristic algorithm for efficient resource allocation in 5g mobile edge clouds," *IEEE Transactions on Mobile Computing (In Press)*, pp. 1–13, 2022.

[33] W. Zhang and J. Yu, "Task offloading strategy in mobile edge computing based on cloud-edge-end cooperation," *Journal of Computer Research and Development (In Chinese)*, vol. 60, no. 2, pp. 371–385, 2023.

[34] X. Zhang, W. Wu, C. Zhang, Y. Cai, S. Yang, and X. Wang, "Energy-efficient computing offloading algorithm for mobile edge computing network," *Journal of Software (In Chinese)*, vol. 34, no. 2, pp. 849–867, 2023.

# A Comprehensive System for Managing Blood Resources Leveraging Blockchain, Smart Contracts, and Non-Fungible Tokens

Khiem H. G.[1], Huong H. L.[*1], Phuc N. T.[1], Khoa T. D.[1], Khanh H. V.[1], Quy L. T.[1], Ngan N. T. K.[2],
Triet N. M.[1], Kha N. H.[1], Anh N. T.[1], Trong. V. C. P.[1], Bang L. K.[1], Hieu D. M.[1], and Bao T. Q.[2]

[1]FPT University, Can Tho City, Vietnam
[2]FPT Polytechnic, Can Tho City, Vietnam

*Abstract*— The escalating demand for blood and its derivatives in the medical field underpins its indispensable nature for disease diagnosis and therapy. Such essential life-giving components are irreplaceable, necessitating a continuous reliance on voluntary blood donors. Existing methodologies primarily address the challenges of blood storage and its logistical distribution among healthcare centers. These conventional strategies lean towards centralized systems, often compromising data transparency and accessibility. Notably, there remains a significant gap in incentivizing and raising awareness among potential and existing donors regarding the life-saving act of blood donation. Recognizing these challenges, we introduce a robust and innovative framework that harnesses the potential of Blockchain technology, coupled with the power of smart contracts. Furthermore, to foster a sustainable blood donation ecosystem, we advocate the shift from traditional paper-based recognition to digitized donor acknowledgment using Non-Fungible Tokens (NFTs). Our novel approach encapsulates four key areas: (a) Introduction of a supply chain oversight mechanism for blood and its derivatives through Blockchain and smart contracts; (b) Development of a digital certification system for blood donors utilizing NFTs; (c) Execution of our suggested framework via smart contracts, offering a tangible proof-of-concept; and (d) Assessment and implementation of the proof-of-concept across four prominent platforms: ERC721 (ETH's NFT), and the Ethereum Virtual Machine (EVM) employing the Solidity language – this encompasses the BNB Smart Chain, Fantom, Polygon, and Celo, aiming to discern the optimal platform compatible with our innovative framework.

*Keywords—Blood donation; blockchain; ethereum; blood products supply chain; smart contract; NFT; ethereum; fantom; polygon; binance smart chain*

## I. INTRODUCTION

Supply chain management, an interdisciplinary field that interlinks various sectors, has witnessed transformational shifts in the digital age, with implications spread across delivery [1], [2], [3], payment systems [4], [5], [6], project dynamics [7], product movement [2], [8], and even ecological waste disposal [9]. One of its paramount manifestations is within the medical landscape, particularly in ensuring the efficient and safe management of blood and its associated products.

Historically, the majority of supply chain models, while sophisticated, have been grounded in traditional logistics and storage paradigms. When we delve into the intricacies of managing biological resources like blood, these models often fall short. Blood, unlike other commodities, has unique storage

requisites, from maintaining a specific temperature range to ensuring an optimal humidity environment, and most critically, adhering to its limited shelf life [10]. These nuances underscore the inadequacies of conventional supply chain mechanisms and highlight an urgent need for innovation.

Enter blockchain technology and smart contracts. Beyond the mainstream applications in finance and business, these technologies harbor immense potential for healthcare. In ensuring a transparent, immutable, and decentralized storage and access system, they promise an enriched donor-recipient relationship. Every single unit of blood can be tracked, from its origin to its end-use, ensuring complete transparency and trustworthiness in the system [11]. But technology alone, as history often reminds us, is insufficient to drive societal change.

Across the globe, the act of blood donation remains both a noble endeavor and a logistical challenge. How does one not only encourage a first-time donation but ensure that the donor returns, given the physiological restrictions that mandate waiting periods between donations? Current incentive structures, while well-intentioned, often falter in ensuring sustained donor engagement. And with medical innovations surging, the demand for blood and its derivatives amplifies, rendering the challenge even more pronounced [12].

It is within this complex mosaic of challenges and opportunities that our research emerges, aiming to not merely innovate but to transform. Our work, grounded in the principles of blockchain, smart contracts, and the dynamism of Non-Fungible Tokens (NFTs), envisions a holistic reimagining of the blood donation landscape.

Our pivotal contributions are:

- Redefining Blood Supply Chain Mechanisms: By integrating blockchain and smart contract technologies, we introduce a more transparent, efficient, and secure system for managing the blood supply chain.

- NFT-driven Electronic Certification: Venturing beyond conventional incentive models, we harness the capabilities of NFTs to create a robust electronic certification system for blood donors. These digital tokens, being unique and easily transferable, provide an innovative solution to the tangible certificate's pitfalls, offering

donors a secure and lasting acknowledgment of their invaluable contribution.

- Proof-of-Concept Realization: Our theoretical formulations are translated into tangible, executable smart contracts, reinforcing the practical viability and applicability of our proposed systems.

- Platform Exploration and Optimization: Conscious of the economic implications, our solutions undergo rigorous deployment trials across platforms supporting the Ethereum Virtual Machine (EVM) infrastructure. Our endeavor seeks not just feasibility but also cost-effectiveness, ensuring that our solutions remain both cutting-edge and accessible.[1]

The undercurrent binding our contributions is the conviction that technology, when thoughtfully applied, can drive societal transformations. By augmenting the blood donation landscape, our research does more than introduce technological innovations; it touches lives, accelerates medical interventions, and champions a cause of profound societal significance.

## II. RELATED WORK

### A. Prior Art in Blood Supply Chain Management via Blockchain

In recent years, Blockchain technology's transformative potential has been tapped to address challenges in blood supply chain management. Notably, Nga et al. [13] pioneered this integration, showcasing a working model implemented on the Hyperledger Fabric platform. Their primary innovation was the facilitation of healthcare professionals to log and secure data directly on the blockchain. Shifting from a centralized storage protocol to a decentralized one, this framework places significant emphasis on ensuring robust security mechanisms. Particularly, as documented by [14], they engineered an authorization process that offers exclusive access to sensitive donor and recipient data only to authenticated users, preserving the privacy sanctity system-wide.

Supplementing this innovative stride, Kim et al. [15] extended the application of Hyperledger Fabric in designing a holistic blood supply chain management system. Their model prioritizes privacy, constructing a well-contained system that oversees the entire blood supply trajectory—from collection to final distribution to medical institutions. Another salient feature they introduced is a donor identification technique to streamline communication for future blood donation drives. However, a noticeable void in their proposal is the absence of granular management processes tailored to distinct blood components, each demanding specific preservation methods and having unique shelf lives.

Lakshminarayanan et al. [16] further explored the Hyperledger Fabric's capabilities, proposing a model accentuating transparency in blood transportation from donors to end recipients. Another intriguing convergence of technologies was demonstrated by Toyoda et al. [17], where they synergized blockchain with Radio Frequency Identification (RFID). In this model, upon blood donation, each unit gets a unique RFID tag,

simplifying access to comprehensive blood-related data, like donation time and location, for both healthcare professionals and recipients.

While many have gravitated towards the Hyperledger Fabric, Ethereum's potential hasn't been overlooked. A compelling use case, delineated by [10], presents an Ethereum-centric decentralized architecture. This structure exclusively empowers certified blood donation centers (CBDC) to manage blood and its components through deployable smart contracts. This system ensures procedural fidelity and plugs potential logistical gaps. An added advantage is the donor's ability to interface with the system using unique identifiers, such as social security numbers, paired with secure passwords.

Zooming into specific blood components, Peltoniemi et al. [18] analyzed the efficacy of decentralized blockchains in plasma management. Their approach ensures meticulous documentation of donor data prior to plasma extraction. Post extraction, an analytical assessment discerns the plasma quality.

In light of the foregoing exploration of blockchain-powered blood supply chain solutions, it's evident that while tremendous progress has been made in rectifying traditional system pitfalls, one persistent challenge remains unaddressed: incentivizing recurring blood donations. Our contribution to this discourse is a multifaceted model amalgamating Blockchain (specifically Ethereum), Smart Contracts, and Non-Fungible Tokens (NFTs). This model doesn't just oversee the blood supply chain but also introduces digital recognition mechanisms, like electronic donor certificates. An in-depth exposition of our model is detailed in the subsequent section.

### B. Blockchain-based Medical Systems

Healthcare has always been a fundamental aspect of human life. With the advancement of technology and a growing concern for patients' data privacy and the immediate need for accessing data during emergencies, blockchain technology has emerged as a promising solution for many of the challenges faced by modern healthcare systems.

*a) Emergency access in healthcare systems:* Son et al. [19] stressed the importance of personal health records (PHR) due to their sensitivity and significance in healthcare. The authors identified the challenges faced during emergencies when it becomes cumbersome for patients to grant medical personnel access to their critical health records. They proposed an emergency access control management system built on the permissioned Hyperledger Fabric blockchain. The system leverages smart contracts to define rules and timeframes to handle emergencies, ensuring patients can restrict data access time.

Similarly, Le [20] introduced the Patient-Chain platform, a blockchain-based patient-centered healthcare system also built on Hyperledger Fabric. The system aims to protect patients' data during emergencies and provides a systematic approach to allow authorized personnel to access patient data during time-sensitive situations.

*b) Medical waste management:* The demand for medical equipment spiked significantly during the COVID-19 pandemic. However, the subsequent waste treatment processes

---

[1]We consciously eschew ETH owing to its exorbitant smart contract execution expenses.

often went overlooked. Le et al. [9] highlighted the independent waste treatment processes in hospitals that lack coordination and data sharing. The authors proposed the Medical-Waste Chain, a decentralized system built using Hyperledger Fabric technology. This system manages the waste treatment processes for used medical equipment and supplies, promoting transparent and efficient interactions between all involved stakeholders.

*c) Blood supply chain management:* With a rising demand for blood supply due to demographic shifts, traditional blood management information systems face challenges, such as the lack of detailed blood data, making the quality, supply, and demand management for blood quite challenging. In response, Le [14] introduced BloodChain, a blockchain-based system that improves blood information management. The system, constructed on Hyperledger Fabric, provides detailed data, including blood consumption and disposal metrics.

Quynh et al. [13] echoed similar sentiments about the changing population structure and its impact on blood supply. They introduced a novel system on Hyperledger Fabric to manage blood information effectively, addressing supply and demand challenges faced by national institutions.

*d) Patient-centered healthcare systems:* Duong [21] identified challenges in current healthcare systems regarding the privacy and sharing of medical data. The authors highlighted the necessity for a secure transaction mechanism to allow patients to monitor and control their health records. Proposing a solution, they introduced a patient-centered healthcare system using smart contracts via blockchain technology, releasing the complete code solution on GitHub to promote reproducibility and further improvement.

In another contribution, Duong [22] proposed a patient-centric system based on smart contracts. Emphasizing patients' control over their health records, the authors used Smart Contract on both Hyperledger Fabric and Ethereum Blockchain to improve care coordination. Through six algorithms, they interacted with different components of the healthcare system, showcasing the system's efficiency through simulation results.

In summary, while blockchain technology offers a plethora of solutions to address various challenges in the healthcare sector, from managing blood supply chains to medical waste, its paramount feature remains in ensuring the privacy and security of patient data. Future research might look into integrating these blockchain-based systems with other emerging technologies to further improve healthcare operations and patient experiences.

## III. METHODOLOGY

This section elucidates the conventional models of blood donation and its associated documentation methods. We further introduce a novel methodology incorporating Blockchain technology, smart contracts, and Non-Fungible Tokens (NFTs) to modernize the system of transporting, storing, and authenticating blood products.

### A. Conventional Blood Donation and Management Process

As depicted in Fig. 1, the conventional blood donation system operates through four primary channels. Donors, de-
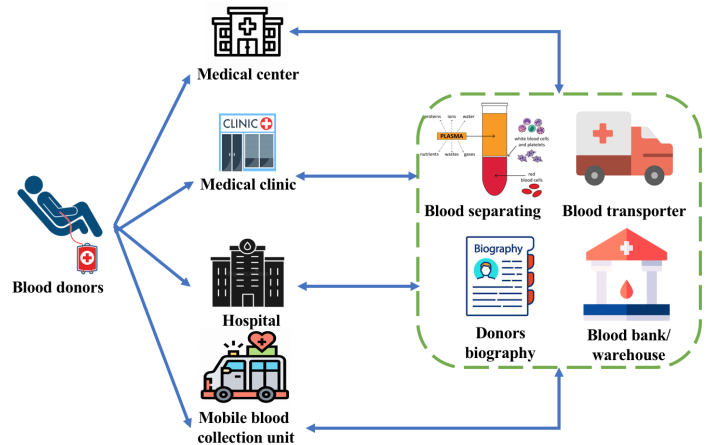


Fig. 1. Conventional system of blood donation and management.

pending on their geographical proximity, have the option to donate at: (a) healthcare centers; (b) medical facilities; (c) hospitals; or (d) portable blood collection stations [23]. The fourth option, (d), is a transient solution such as pop-up stations during weekends or holidays. This approach is not only geared towards encouraging potential donors but also addresses challenges in regions where there are obstacles to blood collection using the first three methods. Once the blood is collected, it is transported to specialized facilities or institutions equipped with blood storage systems. This collected blood undergoes separation into components like red and white blood cells, platelets, and plasma. Simultaneously, donor data is recorded and stored securely for communication purposes.
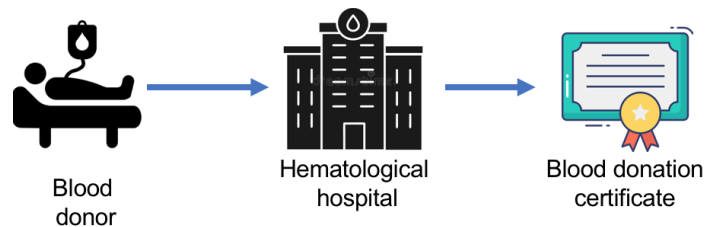


Fig. 2. Conventional blood donor certification.

In terms of documentation, Fig. 2 elucidates the process of obtaining a donor certificate from an institution, such as a hematology center. Such certificates serve as a moral boost for donors. Moreover, they ensure that donors receive equivalent blood volume in situations where they might require it due to certain health conditions. Detailed critiques and evaluations regarding the shortcomings of this method have been discussed in the Introduction[2]. The subsequent subsection outlines our innovative proposal that leverages blockchain, smart contracts, and NFT technology.

### B. Revolutionizing Blood Donation and Management via Blockchain, Smart Contracts, and NFT

The core objective of our research is to formulate an advanced system that enhances blood utilization across med-

---

[2]Refer to our earlier publications for a deeper dive into the challenges of conventional methodologies [14].
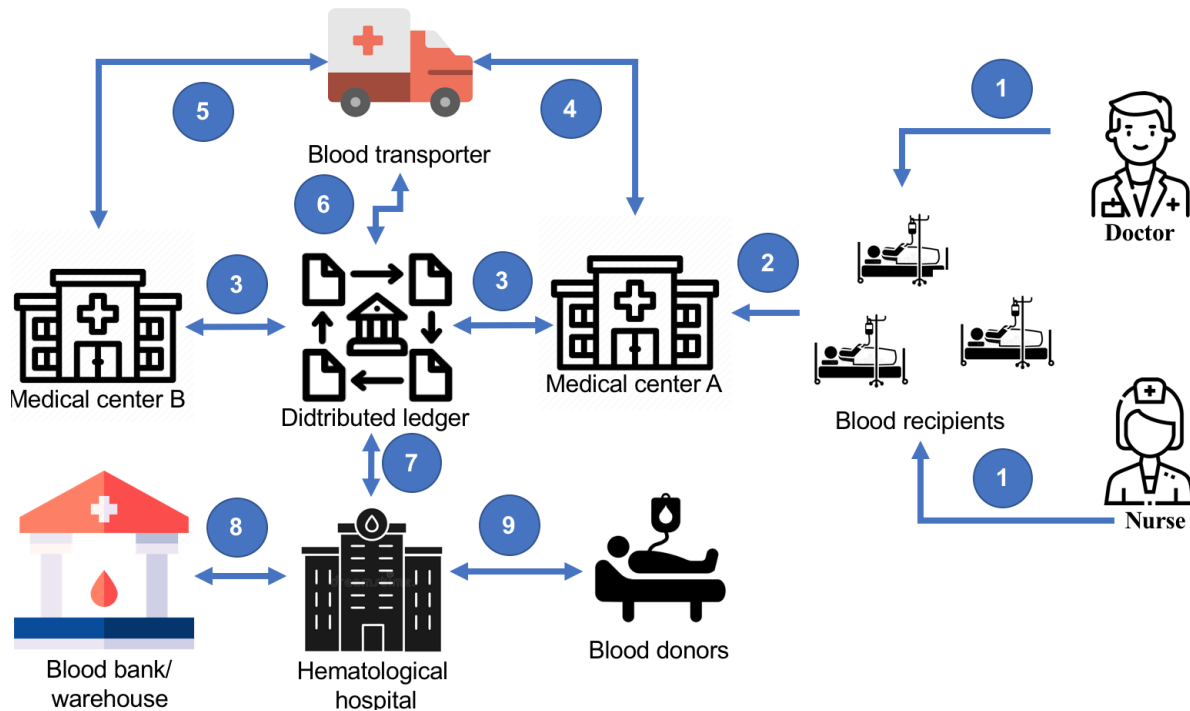
Fig. 3. A novel blood donation and management paradigm utilizing blockchain, smart contract, and NFT technologies.

ical establishments and offers inventive means to motivate individuals to regularly donate. In this context, we propose a dual model that harnesses the capabilities of blockchain, smart contracts, and NFTs to circumvent existing limitations.

Fig. 3 suggests an interconnected model for blood donation and its management among healthcare facilities within a specified region, e.g., a city. The first step encompasses clinical examinations and treatments offered by physicians to their patients, who might be potential recipients of blood. Should there be a necessity for blood, a requisition is forwarded to the concerned institution. Two scenarios can arise: either the institution has an adequate blood stock or faces a shortage. In the latter scenario, the requirement is logged onto a distributed digital ledger. This system then scans affiliated institutions for the requisite blood type. Upon locating a matching facility, a carrier is mobilized. Vital data points such as timings and locations are recorded onto the digital ledger. In situations where local healthcare facilities are devoid of the needed blood type, the system communicates with specialized hematology centers or scans regional blood banks. If there still remains a deficiency, potential donors are contacted for collections.

Fig. 4 delineates the procedure for NFT issuance which serves as a digital blood donation certificate. Before the NFT's generation, donor's consent and institutional validation (e.g., from a hematology center) are imperative. We extend distinct services to each stakeholder, culminating in the creation of a digitalized version of the donor certificate. This data, alongside pertinent documentation, is recorded on the distributed ledger, leading to the production of an NFT via predefined functions in the smart contract.
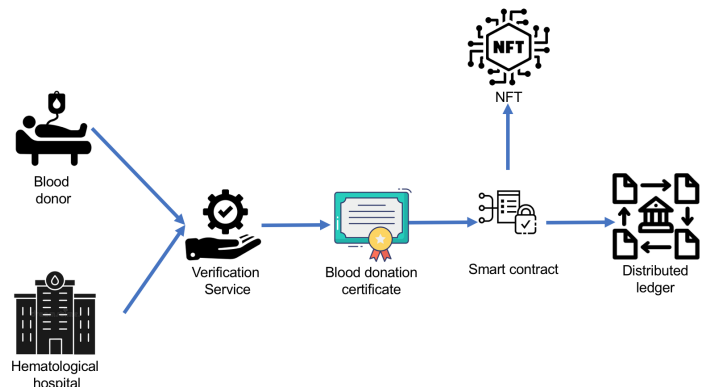


Fig. 4. Process of issuing digital blood donation certificates leveraging NFT technology.

## IV. IMPLEMENTATION

This practical model serves dual purposes: (i) management of blood and its by-products data on the blockchain platform encompassing creation, querying, and updates, (ii) instantiation of NFTs for donor contributions, serving as a motivation for continued blood donation. Moreover, we present the sample of the managing blood resources leveraging on Binance Smart Chain as a deployment sample.

### A. Data and NFT Initialization

As depicted in Fig. 5, the process begins by generating comprehensive data on blood and its derivatives. This encompasses details about the donors, their contact specifics (e.g., address, unique identification code), specifics about blood and its components, and their respective shelf lives. Given the
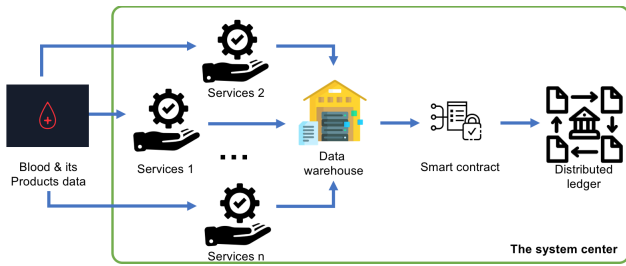
Fig. 5. Process of data and NFT initialization.
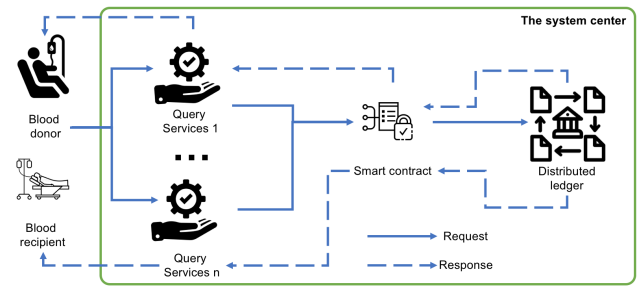


Fig. 6. Data retrieval process.

varying storage needs and lifespans of different blood products, categorization is vital. Moreover, the system archives details about the recipients, blood type requirements, and the medical professionals overseeing the procedures. Concurrent storage support is enabled on the distributed ledger, allowing multiple users to engage simultaneously, thereby reducing latency.

The data structure for a blood component, such as red blood cells, is represented as:

```
redBloodCellsData = {
"donorID": donorID,
"medicalStaffID": medicalStaffID,
"bloodType": blood type,
"institutionID": institutionID,
"volume": volume,
"validityPeriod": validity period,
"packageID": packageID,
"timestamp": timestamp,
"location": current location,
"status": null,
};
```

Besides the primary data attributes, the system monitors the real-time status of blood components in storage. This status attribute indicates if the blood product is in storage or has been dispatched for medical use. This dynamic tracking, combined with time and location data, aids in real-time logistics management.

For initializing NFTs, the structure encapsulates the blood donation details as:

```
NFTBloodDonation = {
"donorID": donorID,
"bloodType": blood type,
"donationCount": donation occurrences,
"totalVolume": accumulated volume donated,
"lastDonationDate": most recent donation date,
"blockchainAddress": blockchain address
};
```

This ensures a comprehensive, immutable record of each donation, aiding in efficient management and donor recognition.

### B. Data Retrieval

Fig. 6 outlines the steps involved in the data retrieval mechanism. Leveraging a distributed model, it permits multiple users to concurrently access the system. Donors and recipients might seek insights into storage processes, donation frequency, or upcoming donation schedules. Medical professionals, on the other hand, might access donor details for outreach or future donation drives.

### C. Data Update Mechanism
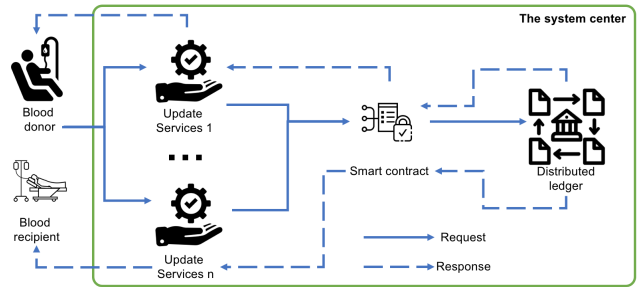


Fig. 7. Procedure for data updates.

As demonstrated in Fig. 7, the data updating procedure only commences post data verification. If the sought data isn't present on the blockchain, a non-availability message is relayed to the user. In case of updates, the process fetches existing data and modifies relevant attributes such as blood volume or donation frequency. For NFTs, any major update triggers the generation of a new NFT, ensuring historical records remain untouched.

### D. Managing Blood Resources using Binance Smart Chain

The Binance Smart Chain (BSC) has been identified as an ideal candidate for managing blood resources, given its compatibility with the Ethereum Virtual Machine (EVM) and its optimized transaction performance. As such, the proposed model is primarily evaluated and implemented on BSC, but compatibility with other platforms is also maintained. Here, we discuss the specifics of the implementation on BSC, showcasing transaction details, NFT creation, and the process of NFT transfers.

Fig. 8 details our deployment of the system on BSC. It showcases attributes essential for evaluating and comparing transaction performance across different blockchain platforms. This snapshot is a representative case, with similar settings applied when deploying on other platforms. Transaction details like the transaction fee, gas limit, and gas price provide a

Fig. 8. A snapshot illustrating transaction details on Binance Smart Chain. The attributes highlight the cost implications and performance of a transaction, specifically for our blood management use case.



Fig. 9. Depicting the NFT creation process on BSC. This highlights the structured format of our NFTs, tailored to represent blood donations and their associated attributes.

comprehensive insight into the cost-effectiveness of operations on the chain.

The NFT creation process, visualized in Fig. 9, follows a structured format. Each NFT is intricately designed to represent blood donations, capturing essential details like the donor's information, blood type, and donation history. Such a tokenized representation not only ensures data integrity and authenticity but also promotes transparency in the system.



Fig. 10. A detailed representation of NFT transfer operations on BSC. The process ensures secure, transparent, and traceable transfer of NFT ownership.

The transfer of NFTs, especially in a sensitive domain like blood resource management, demands high levels of security and traceability. Fig. 10 provides a comprehensive overview of the NFT transfer operations. Leveraging the ERC721 standard ensures that each NFT transfer is not just secure but also accompanied by clear traceability, promoting trust among participants.

While Binance Smart Chain plays a pivotal role in our implementation, it's essential to recognize the versatility of our model. We have deployed and evaluated the system on several EVM-compatible platforms, including Binance Smart Chain[3], Polygon[4], Fantom[5], and Celo[6]. Implementations and results across these platforms, especially focusing on cost metrics like transaction fees and gas utilization, are detailed in the ensuing Evaluation section.

---

[3]https://github.com/bnb-chain/whitepaper/blob/master/WHITEPAPER.md
[4]https://polygon.technology/lightpaper-polygon.pdf
[5]https://whitepaper.io/document/438/fantom-whitepaper
[6]https://celo.org/papers/whitepaper

## V. EVALUATION SCENARIOS

### A. Transaction Fee Analysis

Table I showcases the transaction fees of distinct operations, namely Contract Creation, NFT Creation, and NFT Transfer, across four pivotal blockchain platforms: BNB Smart Chain, Fantom, Polygon, and Celo. These platforms, known for their support of the Ethereum Virtual Machine (EVM), differ significantly in their fee structures.

Contract creation, a foundational operation for initiating any decentralized application, bears varying costs across platforms. BNB Smart Chain requires approximately 0.02731136 BNB, equating to $8.37. This competitive fee is attributed to the Binance Smart Chain's infrastructure and its optimization for reduced costs. Conversely, Fantom, known for its efficient contract deployment, charges a lower fee of 0.009576826 FTM or about $0.001860. Polygon, a Layer-2 scaling solution, boasts an even more affordable rate at 0.006840590024626124 MATIC ($0.01), emphasizing its aptitude for micro-transactions. Finally, Celo, focusing on mobile-centric blockchain solutions, demands a modest 0.0070973136 CELO, translating to around $0.004.

The surge in NFT (Non-Fungible Token) popularity necessitates a comprehension of minting costs. On the Binance Smart Chain, a fee of 0.00109162 BNB or $0.33 is levied for this operation. Fantom's fee structure is notably lower for the same, standing at 0.000405167 FTM ($0.000079). Polygon, with its emphasis on affordable transactions, charges a mere 0.00028940500115762 MATIC, a negligible amount in fiat terms. Celo's rate for NFT creation is comparably minimal at 0.0002840812 CELO or roughly $0.000.

Transferring ownership of NFTs, a procedure that consumes computational resources for validation and recording, also incurs diverse costs across these platforms. BNB Smart Chain's fee is 0.00057003 BNB or $0.18. Fantom's cost stands at 0.0002380105 FTM, approximately $0.000046. Polygon continues its trend of affordable operations, charging 0.000170007500612027 MATIC, which is negligible in fiat currency. Similarly, Celo's fee for this process is 0.0001554878 CELO, equating to about $0.000.

In sum, this detailed exploration of Table I underscores the variable costs of primary blockchain operations across different platforms. It's paramount for stakeholders to not just consider these transaction fees, but also weigh other platform-specific factors, such as security, scalability, and community backing, when determining the most suitable blockchain for their endeavors.

### B. Gas Limit Analysis

Table II distinctly portrays the gas limits for crucial blockchain operations across four salient platforms: BNB Smart Chain, Fantom, Polygon, and Celo. The gas limit is a quintessential parameter, representing the maximum amount of gas units that a sender is willing to expend on a transaction. It's a protective mechanism to ensure that transactions don't unintentionally consume all the sender's funds due to errors in contract logic or malicious intentions.

Starting with the Contract Creation, a cardinal operation that establishes the foundation for decentralized applications:

TABLE I. TRANSACTION FEE

|  | Contract Creation | Create NFT | Transfer NFT |
|---|---|---|---|
| BNB Smart Chain | 0.02731136 BNB ($8.37) | 0.00109162 BNB ($0.33) | 0.00057003 BNB ($0.18) |
| Fantom | 0.009576826 FTM ($0.001860) | 0.000405167 FTM ($0.000079) | 0.0002380105 FTM ($0.000046) |
| Polygon | 0.006840590024626124 MATIC($0.01) | 0.00028940500115762 MATIC($0.00) | 0.000170007500612027 MATIC($0.00) |
| Celo | 0.0070973136 CELO ($0.004 ) | 0.0002840812 CELO ($0.000 ) | 0.0001554878 CELO ($0.000 ) |

TABLE II. GAS LIMIT

|  | Contract Creation | Create NFT | Transfer NFT |
|---|---|---|---|
| BNB Smart Chain | 2,731,136 | 109,162 | 72,003 |
| Fantom | 2,736,236 | 115,762 | 72,803 |
| Polygon | 2,736,236 | 115,762 | 72,803 |
| Celo | 3,548,656 | 142,040 | 85,673 |

TABLE III. GAS USED BY TRANSACTION

|  | Contract Creation | Create NFT | Transfer NFT |
|---|---|---|---|
| BNB Smart Chain | 2,731,136 (100%) | 109.162 (100%) | 57,003 (79.17%) |
| Fantom | 2,736,236 (100%) | 115,762 (100%) | 68,003 (93.41%) |
| Polygon | 2,736,236 (100%) | 115,762 (100%) | 68,003 (93.41%) |
| Celo | 2,729,736 (76.92%) | 109.262 (76.92%) | 59,803 (69.8%) |

- BNB Smart Chain has set its gas limit at 2,731,136. This platform's optimization for rapid and cost-efficient transactions is manifested in its relatively streamlined gas limit, ensuring the smooth deployment of smart contracts without unnecessary overheads.

- Fantom and Polygon, both with a gas limit of 2,736,236 for this operation, have nearly identical values. The similarity might stem from their shared objective of optimizing EVM compatibility and transaction efficiency, ensuring developers migrating from Ethereum find a familiar environment.

- Celo, with a more generous gas limit of 3,548,656, emphasizes flexibility. This platform, renowned for its mobile-centric approach, might accommodate more comprehensive contracts with intricate features, necessitating a higher gas allowance.

Moving to the realm of NFTs, a booming sector within the blockchain industry:

- For NFT Creation, BNB Smart Chain allocates a gas limit of 109,162. Given the proliferation of NFTs on this chain, a harmonized gas limit helps stabilize the costs associated with minting.

- Both Fantom and Polygon, with their synchronized limits of 115,762, demonstrate an equilibrium in accommodating the minting processes, potentially reflecting common optimization strategies.

- Celo, in line with its previously observed trend, sets its limit at 142,040, granting developers more leeway for intricate NFT-related operations.

Lastly, for NFT Transfer:

- BNB Smart Chain, maintaining its ethos of streamlined operations, sets a limit of 72,003, balancing efficiency with the necessary computational power.

- Fantom and Polygon, true to their aforementioned synchronization, both allocate 72,803 units. This congruence underscores their shared emphasis on facilitating swift and seamless NFT transfers without incurring undue costs.

- Celo's value stands at 85,673, slightly higher than the others. This platform's propensity for granting a broader gas berth might be to ensure all encompassing NFT functionalities, including meta-transactions and layered transfers, are seamlessly accommodated.

Table II elucidates the diverse gas limits across blockchain platforms. These figures are not just mere numbers; they embody each platform's philosophy, optimization strategies, and focus areas, guiding developers and stakeholders in their blockchain endeavors.

### C. Gas Used by Transaction Analysis

Table III provides an intricate breakdown of the gas consumption for pivotal operations across BNB Smart Chain, Fantom, Polygon, and Celo platforms. The values illustrate the proportion of the gas limit consumed by each operation, revealing the actual computational overheads associated with the actions. Notably, an operation's efficiency can be deduced by its gas consumption percentage. Lower percentages indicate optimized contract functions, while higher values may hint at the operation's complexity or inefficiencies.

Starting with the pivotal operation of Contract Creation:

- BNB Smart Chain, Fantom, and Polygon all exhibit a consumption of 100%. This denotes that these platforms optimally utilize the gas limit for the operation, ensuring that the smart contracts are deployed efficiently without wastage or excess.

- Celo stands at 76.92%, suggesting that the platform's contract creation process might be optimized further or that the operations contain redundant computations, consuming lesser than the allocated gas limit.

Delving into the NFT realm:

- For NFT Creation, both BNB Smart Chain and Celo consume 76.92% of the gas. It could indicate shared optimization techniques or similar contract structures.

- Fantom and Polygon, with a consumption rate of 100%, indicate an exhaustive use of the allocated gas, mirroring their performance in contract creation. Their contracts for NFT creation might be exhaustive

or meticulously tailored to use the entirety of the allocated gas.

When it comes to NFT Transfer:

- BNB Smart Chain has a consumption rate of 79.17%. This indicates a reasonably efficient transfer operation, ensuring a smooth transition of assets across addresses.

- Fantom and Polygon, with identical figures of 93.41%, suggest a higher computational need or a more comprehensive process to ensure asset security during transfer.

- Celo consumes 69.8% of the gas. This might denote an optimized transfer mechanism or a more straightforward procedure compared to other platforms, leaving a portion of the allocated gas unutilized.

To encapsulate, Table III unearths the intricacies of gas consumption patterns across platforms, serving as a barometer to gauge operational efficiencies and offering invaluable insights to developers and users alike.

### D. Gas Price Analysis

The cost of executing a transaction on a blockchain is determined by the gas price, which is multiplied by the gas used. Gas prices essentially dictate the fee paid to miners or validators for transaction inclusion in a block. Table IV elucidates the set gas prices for different operations on various blockchain platforms.

BNB Smart Chain:

- The gas price remains consistent across all operations, being set at 10 Gwei (or 0.00000001 BNB). Given BNB Smart Chain's commitment to providing scalable and low-cost transactions, a stable gas price ensures predictability for users and developers.

Fantom:

- At 3.5 Gwei (or 0.0000000035 FTM) for all operations, Fantom offers an even lower gas price than BNB Smart Chain. The consistent pricing reflects Fantom's operational efficiency and its design geared towards a high throughput.

Polygon:

- Polygon's gas prices, though varied minutely, hover around 2.5 Gwei. The slight variations, albeit minor, could be due to the inherent floating-point imprecisions or perhaps due to a dynamic gas price setting algorithm, though the former seems more plausible.

Celo:

- The gas prices for Celo operations are set at approximately 2.6 Gwei (0.0000000026 CELO). Interestingly, the maximum fee per gas, capped at 2.7 Gwei, gives users a ceiling for potential fluctuations, ensuring transaction costs remain within predictable bounds.

In summation, gas prices are pivotal in determining the overall cost of a transaction. As platforms strive for mass adoption, ensuring competitive, consistent, and transparent gas prices is essential. It not only fosters trust but also encourages application development and user participation by making operations financially feasible.

## VI. DISCUSSION

The exploration and comparison of the gas metrics across various blockchain platforms, specifically BNB Smart Chain, Fantom, Polygon, and Celo, provide a compelling view of the operational efficiencies, cost structures, and user experiences offered by each. These metrics, while technical, carry profound implications for the broader blockchain ecosystem, developers, and end-users alike. Here, we delve deeper into the repercussions and broader perspectives.

### A. Operational Efficiencies and Scalability

Gas prices: A consistent gas price, as seen in BNB Smart Chain and Fantom, speaks volumes about a platform's predictability. While lower gas prices are invariably attractive for users and developers, consistency ensures that users can predict costs, allowing for better financial planning and resource allocation. The minute variation in Polygon's gas price could be indicative of a more dynamic approach to network congestion and resource management, although this merits further investigation.

Gas used: The efficiency of a blockchain platform can also be gauged by looking at the gas used for each operation. A higher percentage indicates a more efficient utilization of resources, whereas a significantly lower percentage may suggest that transactions are either too complex or the network overestimates the required gas.

### B. Cost Structures

Economic implications: Low and predictable transaction costs, like those of BNB Smart Chain and Fantom, can be major drivers for mass adoption. High transaction costs can deter users, especially for micro-transactions or frequent operations. Economically, for blockchain platforms to find widespread use in daily applications—be it in finance, gaming, or supply chain—keeping transaction costs low is paramount.

Developer attraction: For developers, the economic viability of deploying and running applications on a blockchain platform is essential. Platforms that offer competitive gas prices and consistent cost structures are likely to attract more developers, fostering a richer ecosystem of decentralized applications (DApps).

### C. User Experience and Predictability

The end-user experience is invariably tied to costs. Unexpectedly high transaction costs can deter users, leading to a lack of trust in the platform. As seen with Celo's capped maximum fee per gas, providing users with a cost ceiling ensures that they are not caught off guard by potential price spikes, thus enhancing user trust and experience.

TABLE IV. GAS PRICE

| | Contract Creation | Create NFT | Transfer NFT |
|---|---|---|---|
| BNB Smart Chain | 0.00000001 BNB (10 Gwei) | 0.00000001 BNB (10 Gwei) | 0.00000001 BNB (10 Gwei) |
| Fantom | 0.0000000035 FTM (3.5 Gwei) | 0.0000000035 FTM (3.5 Gwei) | 0.0000000035 FTM (3.5 Gwei) |
| Polygon | 0.000000002500000009 MATIC (2.500000009 Gwei) | 0.00000000250000001 MATIC (2.50000001 Gwei) | 0.000000002500000009 MATIC (2.500000009 Gwei) |
| Celo | 0.0000000026 CELO (Max Fee per Gas: 2.7 Gwei) | 0.0000000026 CELO (Max Fee per Gas: 2.7 Gwei) | 0.0000000026 CELO (Max Fee per Gas: 2.7 Gwei) |

### D. Future Directions

Broadening the scope for mainstream acceptance: As we venture into the broader adoption of blockchain technology, an imperative is to ensure transactions remain swift and economically viable. The present data from the four platforms hints at the directionality of this progression. However, while these platforms seem poised for mainstream integration, there is an evident need for extended empirical studies on a variety of use-cases to further this claim.

Innovations and evolutions on platforms: The dynamism of the blockchain sphere cannot be overstated. Our current analysis captures just a fleeting moment in its evolution. Anticipating the future, it's plausible to expect innovations that can redefine cost structures, enhance scalability, and introduce pioneering pricing strategies. The adaptability of these platforms will be tested, necessitating agile and proactive advancements to keep pace.

Harmonizing cross-platform dynamics: The imminent expansion of the blockchain ecosystem suggests an escalation in inter-platform operations. A profound understanding of individual platform cost structures is essential to streamline these multi-chain interactions and ensure economically efficient cross-communication.

Future Explorations and Implementations:

### E. A Glimpse into the Upcoming Endeavors: Future Explorations and Implementations

#### 1) Delving into Advanced Algorithms and Data Structures:

- Purpose: To probe deeper into the blockchain dynamics and bring to light the implications of more sophisticated processes on transactional overheads.

- Highlight: A particular emphasis will be placed on encryption mechanisms. Given their significance in ensuring data security and confidentiality, it's imperative to understand their transactional costs in the blockchain realm.

#### 2) Real-world Deployment of Our Proposed Model:

- Objective: To transition from theoretical frameworks to real-world applications, offering tangible solutions that can be assessed and refined.

- Case in point: We're gearing up to integrate a recommendation system on the FTM mainnet. This move seeks to harness the potential of the platform while testing the feasibility and efficiency of our model in a live environment.

#### 3) Addressing Privacy-Related Complexities:

- Context: In today's digital age, user privacy and data protection have soared in importance. However, our current research hasn't delved deeply into this domain.

- Future directions: We'll be diving into:
  - Access control mechanisms [24], [25]: Exploring how permissions are granted or denied within the blockchain, ensuring only authorized entities can access pertinent information.
  - Dynamic policy frameworks [26], [27]: Understanding how policies that govern data access and usage can be dynamically altered, offering flexibility while maintaining security.

#### 4) Infrastructure-Driven Approaches: Amplifying User Interactivity and System Efficiency:

- Objective: To enhance the user experience, making it more interactive, efficient, and user-centric.

- Strategies under consideration include:
  - gRPC [28], [29]: A high-performance, open-source framework that can potentially supercharge remote procedure calls, ensuring seamless communication between services.
  - Microservices architecture [30], [31]: Breaking down an application into small, loosely coupled services, each running its process, enabling swift deployments and scaling.
  - Dynamic message transmissions [32]: Adapting the mode and format of message transmissions based on real-time requirements and constraints.
  - Brokerless systems [33]: Direct communication mechanisms eliminating intermediaries, aiming to reduce latencies and enhance data transmission rates.

At its core, the incorporation of these systems and approaches is about amplifying user interactions, making the systems more intuitive, responsive, and efficient, potentially through strategies such as API-driven calls.

In sum, the implications of our current gas metrics study pave the way for a host of future explorations. As we advance, the amalgamation of these findings will be instrumental in tailoring platform strategies, aligning developer priorities, and refining user experiences.

## VII. CONCLUSION

By harnessing the transformative capabilities of blockchain technology, smart contracts, and Non-Fungible Tokens (NFTs),

our work offers an innovative reimagination of the blood donation paradigm. Our contributions, including the integration of blockchain in the blood supply chain, the introduction of NFT-driven electronic certification for donors, and the realization of these concepts through proof-of-concept smart contracts, underscore the promise our solutions hold.

Additionally, our commitment to platform optimization, particularly through rigorous deployment trials across Ethereum Virtual Machine (EVM) supportive platforms, emphasizes the tangible and practical significance of our research. Our decision to sidestep Ethereum due to its high cost implications epitomizes our dedication to ensuring that our innovations are not just technologically advanced, but economically viable and accessible.

In sum, our research transcends mere technological advancements. By intertwining technology with a cause as noble as blood donation, we aspire to drive change, save lives, and amplify the significance of every donor's invaluable contribution. As we look forward, we remain optimistic about the transformative impact of our work, not just on the medical landscape but on society at large.

### References

[1] X. S. Ha, T. H. Le, T. T. Phan, H. H. D. Nguyen, H. K. Vo, and N. Duong-Trung, "Scrutinizing trust and transparency in cash on delivery systems," in *International Conference on Security, Privacy and Anonymity in Computation, Communication and Storage.* Springer, 2020, pp. 214–227.

[2] X. S. Ha, H. T. Le, N. Metoui, and N. Duong-Trung, "Dem-cod: Novel access-control-based cash on delivery mechanism for decentralized marketplace," in *2020 IEEE 19th International Conference on Trust, Security and Privacy in Computing and Communications (TrustCom).* IEEE, 2020, pp. 71–78.

[3] H. T. Le, N. T. T. Le, N. N. Phien, and N. Duong-Trung, "Introducing multi shippers mechanism for decentralized cash on delivery system," *International Journal of Advanced Computer Science and Applications*, vol. 10, no. 6, 2019.

[4] H. X. Son and E. Chen, "Towards a fine-grained access control mechanism for privacy protection and policy conflict resolution," *International Journal of Advanced Computer Science and Applications*, vol. 10, no. 2, 2019.

[5] N. Duong-Trung, X. S. Ha, T. T. Phan, P. N. Trieu, Q. N. Nguyen, D. Pham, T. T. Huynh, and H. T. Le, "Multi-sessions mechanism for decentralized cash on delivery system," *Int. J. Adv. Comput. Sci. Appl*, vol. 10, no. 9, 2019.

[6] N. T. T. Le, Q. N. Nguyen, N. N. Phien, N. Duong-Trung, T. T. Huynh, T. P. Nguyen, and H. X. Son, "Assuring non-fraudulent transactions in cash on delivery by introducing double smart contracts," *International Journal of Advanced Computer Science and Applications*, vol. 10, no. 5, pp. 677–684, 2019.

[7] H. H. Luong, T. K. N. Huynh, A. T. Dao, and H. T. Nguyen, "An approach for project management system based on blockchain," in *International Conference on Future Data and Security Engineering.* Springer, 2021, pp. 310–326.

[8] K. L. Quoc, H. K. Vo, L. H. Huong, K. H. Gia, K. T. Dang, H. L. Van, N. H. Huu, T. N. Huyen, L. Van Cao Phu, D. N. T. Quoc *et al.*, "Sssb: An approach to insurance for cross-border exchange by using smart contracts," in *International Conference on Mobile Web and Intelligent Information Systems.* Springer, 2022, pp. 179–192.

[9] H. T. Le *et al.*, "Medical-waste chain: a medical waste collection, classification and treatment management by blockchain technology," *Computers*, vol. 11, no. 7, p. 113, 2022.

[10] M. Çağlıyangil, S. Erdem, and G. Özdağoğlu, "A blockchain based framework for blood distribution," in *Digital Business Strategies in Blockchain Ecosystems.* Springer, 2020, pp. 63–82.

[11] N. Duong-Trung, H. X. Son, H. T. Le, and T. T. Phan, "Smart care: Integrating blockchain technology into the design of patient-centered healthcare systems," in *Proceedings of the 2020 4th International Conference on Cryptography, Security and Privacy*, ser. ICCSP 2020, 2020, p. 105–109.

[12] E. J. Baek, H. O. Kim, S. Kim, Q.-E. Park, and D.-J. Oh, "The trends for nationwide blood collection and the supply of blood in korea during 2002 2006," *The Korean Journal of Blood Transfusion*, vol. 19, no. 2, pp. 83–90, 2008.

[13] N. T. T. Quynh *et al.*, "Toward a design of blood donation management by blockchain technologies," in *Computational Science and Its Applications–ICCSA 2021: 21st International Conference, Cagliari, Italy, September 13–16, 2021, Proceedings, Part VIII 21.* Springer, 2021, pp. 78–90.

[14] H. T. Le *et al.*, "Bloodchain: a blood donation network managed by blockchain technologies," *Network*, vol. 2, no. 1, pp. 21–35, 2022.

[15] S. Kim and D. Kim, "Design of an innovative blood cold chain management system using blockchain technologies," *ICIC Express Letters, Part B: Applications*, vol. 9, no. 10, pp. 1067–1073, 2018.

[16] S. Lakshminarayanan, P. Kumar, and N. Dhanya, "Implementation of blockchain-based blood donation framework," in *International Conference on Computational Intelligence in Data Science.* Springer, 2020, pp. 276–290.

[17] K. Toyoda, P. T. Mathiopoulos, I. Sasase, and T. Ohtsuki, "A novel blockchain-based product ownership management system (poms) for anti-counterfeits in the post supply chain," *IEEE access*, vol. 5, pp. 17 465–17 477, 2017.

[18] T. Peltoniemi and J. Ihalainen, "Evaluating blockchain for the governance of the plasma derivatives supply chain: How distributed ledger technology can mitigate plasma supply chain risks," *Blockchain in Healthcare Today*, 2019.

[19] H. X. Son, T. H. Le, N. T. T. Quynh, H. N. D. Huy, N. Duong-Trung, and H. H. Luong, "Toward a blockchain-based technology in dealing with emergencies in patient-centered healthcare systems," in *Mobile, Secure, and Programmable Networking: 6th International Conference, MSPN 2020, Paris, France, October 28–29, 2020, Revised Selected Papers 6.* Springer, 2021, pp. 44–56.

[20] H. T. Le *et al.*, "Patient-chain: patient-centered healthcare system a blockchain-based technology in dealing with emergencies," in *International Conference on Parallel and Distributed Computing: Applications and Technologies.* Springer, 2021, pp. 576–583.

[21] N. Duong-Trung *et al.*, "Smart care: integrating blockchain technology into the design of patient-centered healthcare systems," in *Proceedings of the 2020 4th International Conference on Cryptography, Security and Privacy*, 2020, pp. 105–109.

[22] ——, "On components of a patient-centered healthcare system using smart contract," in *Proceedings of the 2020 4th International Conference on Cryptography, Security and Privacy*, 2020, pp. 31–35.

[23] H. Le Van, H. K. Vo, L. H. Huong, P. N. Trong, K. T. Dang, K. H. Gia, L. V. C. Phu, D. N. T. Quoc, N. H. Tran, H. T. Nghia10 *et al.*, "Blood management system based on blockchain approach: A research solution in vietnam," *IJACSA*, vol. 13, no. 8, 2022.

[24] H. X. Son, M. H. Nguyen, H. K. Vo *et al.*, "Toward an privacy protection based on access control model in hybrid cloud for healthcare systems," in *International Joint Conference: 12th International Conference on Computational Intelligence in Security for Information Systems (CISIS 2019) and 10th International Conference on EUropean Transnational Education (ICEUTE 2019).* Springer, 2019, pp. 77–86.

[25] H. X. Son and N. M. Hoang, "A novel attribute-based access control system for fine-grained privacy protection," in *Proceedings of the 3rd International Conference on Cryptography, Security and Privacy*, 2019, pp. 76–80.

[26] S. H. Xuan, L. K. Tran, T. K. Dang, and Y. N. Pham, "Rew-xac: an approach to rewriting request for elastic abac enforcement with dynamic policies," in *2016 International Conference on Advanced Computing and Applications (ACOMP)*. IEEE, 2016, pp. 25–31.

[27] H. X. Son, T. K. Dang, and F. Massacci, "Rew-smt: a new approach for rewriting xacml request with dynamic big data security policies," in *International Conference on Security, Privacy and Anonymity in Computation, Communication and Storage*. Springer, 2017, pp. 501–515.

[28] L. T. T. Nguyen *et al.*, "Bmdd: a novel approach for iot platform (broker-less and microservice architecture, decentralized identity, and dynamic transmission messages)," *PeerJ Computer Science*, vol. 8, p. e950, 2022.

[29] L. N. T. Thanh *et al.*, "Toward a security iot platform with high rate transmission and low energy consumption," in *International Conference on Computational Science and its Applications*. Springer, 2021.

[30] ——, "Toward a unique iot network via single sign-on protocol and message queue," in *International Conference on Computer Information Systems and Industrial Management*. Springer, 2021.

[31] L. N. T. Thanh, N. N. Phien, T. A. Nguyen, H. K. Vo, H. H. Luong, T. D. Anh, K. N. H. Tuan, and H. X. Son, "Ioht-mba: An internet of healthcare things (ioht) platform based on microservice and brokerless architecture," *International Journal of Advanced Computer Science and Applications*, vol. 12, no. 7, 2021. [Online]. Available: http://dx.doi.org/10.14569/IJACSA.2021.0120768

[32] L. N. T. Thanh *et al.*, "Uip2sop: A unique iot network applying single sign-on and message queue protocol," *IJACSA*, vol. 12, no. 6, 2021.

[33] L. N. T. Thanh, N. N. Phien, H. K. Vo, H. H. Luong, T. D. Anh, K. N. H. Tuan, H. X. Son *et al.*, "Sip-mba: A secure iot platform with brokerless and micro-service architecture," 2021.

# An Enhanced CoD System Leveraging Blockchain, Smart Contracts, and NFTs: A New Approach for Trustless Transactions

Phuc N. T. (*)[1], Khanh H. V.[1], Khoa T. D.[1], Khiem H. G.[1], Huong H. L.[1], Ngan N. T. K.[2],
Triet N. M.[1], Kha N. H.[1], Anh N. T.[1], Trong. V. C. P.[1], Bang L. K.[1], Hieu D. M.[1], and Quy L. T.(*)[1]

[1]FPT University, Can Tho City, Vietnam
[1]FPT Polytechnic, Can Tho City, Vietnam

*Abstract*—The global transportation of goods has evolved in response to varied economic demands. The rapid progression of modern scientific and technological innovations offers a shift from traditional shipping paradigms. Current systems, whether domestic like Cash-on-Delivery (CoD) or international such as Letter-of-Credit, necessitate trust-building through an intermediary—be it a carrier or a financial institution. While these conventional systems provide certain benefits, they inherently present several challenges and potential vulnerabilities, affecting both sellers and buyers. The introduction of blockchain technology and smart contracts has been explored as a viable alternative to bypass these intermediaries. However, simply removing the shipping intermediary presents its own set of issues, particularly when disputes arise. Notably, the shipper remains unaffected in situations of contention. Consequently, some models are now incorporating the shipper's role, either as a singular entity or in collaboration with others. Yet, a considerable number of these models still depend on an external trusted party for conflict resolution. Our study introduces a unique framework, blending the robustness of blockchain, the enforceability of smart contracts, and the authenticity assurance of NFTs. This system creates a streamlined CoD operation encompassing the seller, shipper, and buyer, using NFTs to produce digital receipts, guaranteeing both proof-of-purchase and a security deposit. Furthermore, our system provides an inherent mechanism for dispute resolution. Key contributions of our work including i) The design of a novel CoD system anchored on blockchain and smart contract capabilities; ii) The incorporation of Ethereum-based NFT (specifically, ERC721) for securely logging package information; iii) The development of smart contracts that facilitate NFT generation and transfer between transactional entities; and iv) Performance evaluation and deployment of these contracts across multiple EVM-compatible platforms such as BNB Smartchain, Fantom, Celo, and Polygon, establishing the optimal environment for our innovative system.

*Keywords*—*Letter-of-credit; cash-on-delivery; blockchain; smart contract; NFT; Ethereum; Fantom; polygon; binance smart chain*

## I. Introduction

The intricate world of shipping and logistics has always revolved around trust and verifiability, historically hinging on the foundational rapport either between buyer and seller or embedded within the trust framework of a shipping entity, notably the shipper [1]. Regrettably, within these traditional paradigms, numerous challenges have surfaced, casting a shadow on the reliability of transactions, especially in the context of international trade.

For instance, consider the Letter-of-Credit (LoC) model, a time-tested mechanism used in international trade. To elucidate, let's sketch a scenario involving a Vietnamese exporter, specializing in cashew nuts, and an importing entity situated in Italy. While seemingly straightforward, the mechanics of their transaction heavily rely on a neutral third party, conventionally a bank, to validate and authenticate the dealings.[1] The fragile nature of this process becomes glaringly evident when crucial documents, say the LoC, go missing. The consequences can be dire, as evidenced by a 2021 event involving potential financial losses in a Vietnamese cashew shipment to Italy, all precipitated by the unavailability of requisite documents.[2] Fortunately, swift diplomatic intervention averted a crisis. Yet, the incident remains a poignant testimony to inherent systemic frailties.

On the domestic front, where the Cash-on-Delivery (CoD) model reigns supreme, sellers are ensnared in a web of dependency on shipping companies. Under this system, profits from goods sold are typically remitted to the sellers either periodically or upon hitting predetermined financial ceilings. However, this trust-dependent system has shown its flaws. A poignant case from Vietnam during 2017-2018 involving GNN Express highlighted the vulnerability, as funds intended for sellers were misused by the shipping entity.[3]

Such systemic vulnerabilities have instigated an earnest quest for robust, technology-driven mechanisms in the shipping sector. The genesis of Bitcoin in 2009 marked a paradigm shift, championing a decentralized, transparent Peer-to-Peer transactional ecosystem reinforced by the Proof-of-Work (PoW) consensus mechanism [2].

Building on this momentum, Ethereum entered the scene, revolutionizing the landscape with the introduction of smart contracts—autonomous, self-regulating contracts, where contractual terms and conditions transmute into programmable code lines.[4] This technological marvel birthed transactional frameworks such as localEthereum in 2017, advocating for

---

[1]For reasons aligned with information security and confidentiality, we have intentionally refrained from naming the specific companies involved in these transactions from Vietnam and Italy.

[2]https://vietnamnet.vn/en/100-containers-of-cashew-nuts-exported-to-italy-suspected-of-being-scammed-821553.html

[3]https://vir.com.vn/gnn-scandal-rocks-delivery-segment-62710.html

[4]https://ethereum.org/en/whitepaper/

payment paradigms rooted in the Solidity language.[5] While several innovative models sprouted, Ethereum's technological acumen found resonance in other platforms, leading to the creation of EVM-integrated platforms, heralding a new era of smart contract adaptability.

Yet, the path is not devoid of hurdles. A recurring critique of many frameworks has been their apparent sidelining of a crucial player in the shipping process: the shipper. Excluding them could muddle dispute resolution processes between sellers and buyers [3]. Recognizing this gap, subsequent studies championed the seamless incorporation of shippers via blockchain and smart contracts [4]. However, integrating shippers isn't the panacea; challenges like potential package damages during transit loom large [5].

Addressing this multifaceted issue is our primary research impetus. We harness the potential of NFT technology to meticulously encapsulate package particulars, ensuring a transparent and accountable transfer process from sellers to buyers, with shippers playing a pivotal role. The cornerstones of our research are: (a) architecting a holistic shipping framework anchored in blockchain technology and enriched with smart contracts; (b) engineering a meticulous Ethereum-based NFT mechanism (specifically ERC721) for comprehensive package information cataloging; (c) the meticulous design and deployment of NFT-empowered smart contracts, enabling seamless transactional experiences between stakeholders; and (d) rigorously assessing the performance of these smart contracts across a spectrum of EVM platforms - specifically, we install a recommendation system on four popular blockchain platforms today, supporting Ethereum Virtual Machine (EVM), including Binance Smart Chain (BNB Smart Chain)[6]; Polygon [7]; Fantom [8]; and Celo [9]. [10]

## II. PRELIMINARIES

### A. Understanding Blockchain

Blockchain gained prominence with Bitcoin's debut in 2008, presented by Nakamoto [2]. It serves as a distributed, credible, and transparent ledger. Within a peer-to-peer network, a blockchain system distributes transaction information across multiple computing devices. This facilitates a robust link between transaction participants, eliminating traditional intermediaries like banks [6].

Presently, blockchains are categorized into Public, Private, and Consortium. Public blockchains, like Bitcoin and Ethereum, are open for all, even anonymous participants, to validate transactions, introduce new ones, and ensure the authenticity of existing data. In contrast, private blockchains like GemOS, MultiChain, Ripple, and Eris restrict participation to authorized members. Consortium blockchains merge attributes from both types. They are designed for business needs, balancing openness with security. Examples include Hyperledger Fabric [7] and the private configurations of Ethereum [8].

---

[5]https://docs.soliditylang.org/en/v0.8.17/

[6]https://github.com/bnb-chain/whitepaper/blob/master/WHITEPAPER.md

[7]https://polygon.technology/lightpaper-polygon.pdf

[8]https://whitepaper.io/document/438/fantom-whitepaper

[9]https://celo.org/papers/whitepaper

[10]The ETH platform was consciously excluded due to the prohibitive costs associated with smart contract operations.

### B. Key Blockchain Platforms

*1) Ethereum:* Ethereum, as described in [9], is a distributed platform that facilitates the execution of smart contracts using the Solidity language. Powered by the Ethereum Virtual Machine (EVM), Ethereum extends its capabilities to decentralized finance (DeFi), establishing protocol-bound conditions.

*2) Hyperledger fabric:* Hyperledger Fabric, an open-source solution [7], is tailored for enterprise requirements. With its distinct architecture, it supports dual modes—public and private blockchains. Unlike Ethereum's reliance on EVM, Fabric employs Docker containers termed "ChainCode" for smart contract execution, offering compatibility with Java and Go, which simplifies development and lowers operational costs.

*3) Celo:* Celo is a decentralized platform prioritizing mobile access and stability of value. While it is EVM-compatible, it differentiates itself with a mobile-first approach. The platform incorporates stable-value tokens, ensuring that transaction fees are predictable.

*4) Fantom:* Fantom is a high-performance, scalable, and secure smart contract platform. Leveraging its unique Lachesis Protocol, it guarantees low time-to-finality. Being EVM-compatible means developers familiar with Ethereum can easily transition to Fantom.

*5) Matic (Polygon):* Polygon, formerly known as Matic, offers a scalable and interoperable framework. While it started as an Ethereum sidechain, it has evolved to support multiple chains. Its EVM compatibility and commitment to scalability make it a preferred choice for many decentralized applications.

### C. Decentralized Logic: Smart Contracts

Smart contracts, known as chaincode in Hyperledger Fabric, digitally facilitate, verify, or enforce credible transactions. These self-executing contracts embed the terms directly within the code. In decentralized applications, they serve as algorithmic agents, functioning like traditional contracts.

*1) Distinctive features:* Smart contracts exhibit several traits:

- Decentralization: Stored across the Ethereum network, contrasting centralized solutions.

- Predictability: Act only under stipulated conditions, maintaining consistent outcomes.

- Autonomy: Automate tasks, staying dormant until activated.

- Immutable Nature: Once deployed, they're unchangeable. However, they can be rendered inactive if preprogrammed.

- Versatility: Programmable before deployment, they cater to diverse decentralized applications.

- Trustless Operations: Enable interactions without mutual trust, as blockchain validates data accuracy.

- Openness: Being on a public ledger, their code is visible to all but remains unalterable.

*2) Functionality overview:* A smart contract's functionality parallels that of a vending machine. It awaits the right conditions, then executes. Assets and terms are encrypted into a blockchain block. Upon activation, the contract follows the encoded logic, autonomously ensuring term adherence.

*3) Advantages:*

- Efficient Cost Structures: Smart contracts streamline processes that conventionally demand intermediaries. By eliminating middlemen, like banks or notaries, there's a direct reduction in associated costs and fees. Transactions are executed automatically when predetermined conditions are met, ensuring that users only bear the essential costs of the contract's execution.

- Adaptive Terms for User Convenience: Smart contracts are designed to be programmable, granting them a degree of flexibility unparalleled by traditional contracts. This adaptability allows parties to customize terms according to their specific needs. Whether it's payment schedules, compliance criteria, or conditional operations, smart contracts can be tailored to handle diverse scenarios, enhancing user experience and satisfaction.

- Complete Transparency and Clarity in Transactions: Being on a blockchain, every smart contract's terms and transactions are transparent to all involved parties. This ensures that every stakeholder can verify transaction details, reducing ambiguities and mistrust. The open nature of public blockchains further enhances transparency, as any external observer can validate the contract's operation, fostering trust and collaboration.

- Unwavering Reliability and Minimal External Interference: Once deployed on the blockchain, a smart contract is immutable. This means that without the consensus of network participants, it cannot be altered, ensuring its credibility. The decentralized nature of blockchains also ensures that no single entity has control over the contract, making it resistant to censorship, fraud, and undue interference.

- Speedy, Straightforward Deployment and Execution: Traditional contracts can be time-consuming due to manual processes, verifications, and approvals. In contrast, smart contracts automatically execute when their conditions are met. This automation, combined with the power of blockchain technology, leads to faster transactions and contract completions. Tools like Remix simplify the development and deployment, further accelerating the entire process.

*4) Solidity and related tools:* Solidity, inspired by languages like JavaScript, C++, and Python, caters to smart contract creation for the EVM. It supports complex types, inheritance, and libraries.

Web3.js serves as a bridge for Ethereum interactions, akin to how jQuery interacts with web servers. It facilitates Ether transfers, smart contract interactions, and more, relying on JSON RPC to communicate with Ethereum nodes.

Remix, a development environment for Solidity, assists in contract drafting, compilation, and debugging. It provides tools for contract deployment and transaction simulations.

### D. Chosen Platforms for Implementation

Our research showcases the Letter-of-credit Chain's proof-of-concept on Ethereum, Binance Smart Chain, and Fantom.

*1) Binance Smart Chain:* Binance Smart Chain (BSC) is an evolution of the original Binance Chain, designed to run parallelly. Like Ethereum, BSC extends its capabilities to DApps and can be deployed on EVM-compatible platforms. BSC employs the Proof of Staked Authority (PoSA) model, a combination of Proof of Authority and Proof of Stake. Validators stake BNB tokens and earn rewards for validations. The seamless integration between Binance Chain and BSC ensures asset interoperability, benefiting from fast transactions and EVM's capabilities.

*2) Celo:* Celo emphasizes on financial tools accessible via mobile phones. Supporting EVM-compatible smart contracts, its primary aim is to diminish financial barriers and simplify access.

*3) Fantom:* Prioritizing speed and security, Fantom provides a scalable smart contract platform. It ensures swift transaction confirmations using its Lachesis Protocol, making it a viable option for various decentralized applications.

*4) Matic (Polygon):* Polygon provides a framework for building and linking Ethereum-compatible blockchain networks. Its primary focus lies in scalability and instant blockchain transactions, catering to a multitude of DApps.

### III. RELATED WORK

Blockchain technology has increasingly found applications in domains requiring secure and transparent interactions among multiple stakeholders. This section provides an overview of these applications, culminating in the emergence of blockchain-based freight models that incorporate Non-Fungible Tokens (NFTs).

### A. Blockchain in Delivery and Transactional Systems

Historically, blockchain has been explored as a solution to problems in various delivery systems. Some notable examples include:

- *Cash-on-Delivery*: Blockchain has been employed to address challenges in cash-on-delivery systems, ensuring both payment security and delivery assurance [10], [11].

- *Letter-of-Credit*: Blockchain's immutability and transparency features make it suitable for modernizing Letter-of-Credit mechanisms, enhancing trust among parties [12], [13].

- *Traditional Delivery*: The technology also aids in streamlining traditional delivery processes by creating clear, tamper-proof records [5], [14].

## B. Blockchain in Healthcare

Beyond delivery systems, the need for transparency and security has made blockchain a favorite for healthcare applications:

- Traditional healthcare systems leverage blockchain for securely storing and accessing patient records, ensuring both patient privacy and data integrity [15], [16].

- Blockchain's transparent and immutable nature has led to its use in the supply chain management for blood and related products, ensuring traceability and accountability [17], [18].

- There are also systems in place that give patients control over their information, promoting a patient-centric approach to healthcare [19].

## C. Bitcoin and its Limitations

Introduced in 2009, Bitcoin was a pioneering system that facilitated trust-less peer-to-peer payments [20]. However, Bitcoin's reliance on the Proof-of-Work (PoW) consensus algorithm led to significant operational costs, both monetary and environmental [21]. The system's constraints, particularly its limited throughput and associated high fees for transaction validations, led to the search for alternative blockchain solutions.

## D. Emergence of Ethereum and Smart Contracts

In response to Bitcoin's limitations, Ethereum emerged as a versatile platform, introducing the concept of smart contracts. These self-executing contracts, with terms directly written into code, enabled more sophisticated and customizable transactions. Ethereum's introduction of the Solidity programming language further empowered developers to create advanced applications on the blockchain. Additionally, Ethereum showcased improved system performance compared to Bitcoin [4].

## E. Decentralized Exchange Platforms

Platforms like Local Ethereum [22] and Open Bazaar [23] aimed to facilitate trust-less exchanges between buyers and sellers. While Local Ethereum focused on a direct barter system, Open Bazaar introduced a third-party, the moderator, enhancing transactional trust. These platforms emphasized transparency, ensuring all members could monitor ongoing transactions, even if not directly involved.

However, these systems' reliance on predefined smart contracts meant inflexibility in the transaction process. Any dispute would require an external trusted party for resolution. This limitation prompted the exploration of adaptable smart contract solutions like the "middleman" [24], offering dynamic contracts with penalties for breaches.

## F. Broadening the Scope: Beyond Traditional Buyer-Seller Models

Ethereum's decentralized applications (Dapps) started considering more participants in transactional models, like shippers or shipping companies [25]. This shift in perspective highlighted the pivotal role of shippers in the transactional ecosystem. However, these models also introduced complexities in arbitration, requiring parties to post deposits as assurance against potential disputes [3], [26].

## G. Our Contribution

In light of the aforementioned challenges and developments, we propose a novel blockchain-based freight model integrating NFT certificates. In our model, unique NFTs are generated upon item shipment, creating a secure, transparent, and traceable record of each transaction.

## IV. Approach

### A. Preliminary: Traditional Freight Transport Modalities

In specific regions, the logistics and shipment processes are overseen and authorized by specialized transport entities. These entities may perform diverse roles—either solely ensuring product delivery or overseeing the financial exchange from the consumer to the vendor. In the model depicted in Fig. 1, the consumer commits the entire invoice payment upfront. This model signifies that the transportation company's primary responsibility is the physical delivery, devoid of any financial intermediation. The outlined process seamlessly moves from invoice consolidation to packaging, and finally, product distribution to the end consumer.

Conversely, the Cash-on-Delivery (CoD) model, prevalent in several regions, is more vendor-centric. Here, transportation companies play a pivotal role in not just delivering but also managing payment collections, as illustrated in Fig. 2. Although the CoD model ensures payment upon successful delivery, it brings forth specific risks for the merchants.

As delineated in the preceding sections, traditional freight systems possess inherent challenges. Our novel contribution aims at an intricate blend of blockchain, NFTs, and smart contracts to modernize and secure the transportation model, safeguarding against potential discrepancies among stakeholders (e.g., vendor, consumer, courier).

### B. Revolutionizing Freight: The Blockchain, NFT, and Smart Contract Fusion

Our proposal, visualized in Fig. 3, hinges on three pivotal technologies: blockchain for transparent and immutable transaction recording, NFTs as digital certificates vouching for consensual agreements, and smart contracts automating contractual obligations. This amalgamation targets the eradication of reliance on central trust entities, even in conflict scenarios.

The process initiates with the vendor, who is mandated to deposit a security amount. This ensures that the product aligns with the information and quality delineated in the smart contract. The logistics company, responsible for managing couriers, deposits a fee to safeguard against potential risks like misplacement, product damage, or insolvency. The consumer's deposit encompasses the logistics fee and a partial product deposit, the latter serving as a safeguard against arbitrary purchase cancellations.

As Fig. 3 suggests, the vendor initiates the process by cataloging the product's specifics (e.g. weight, unit price,
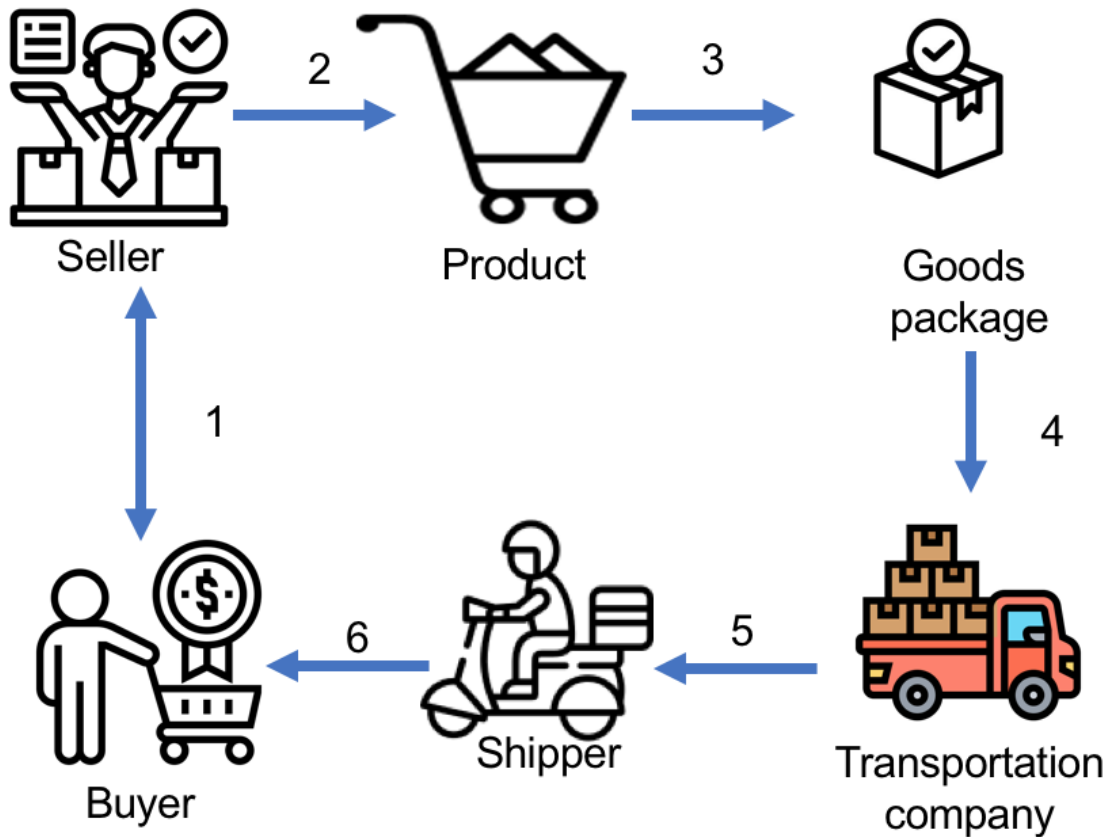
Fig. 1. Traditional framework involving a transportation entity in freight movement.



Fig. 2. Conventional Cash-on-Delivery (CoD) mechanism in freight transport.

type) into the system. Leveraging these details, the system's underlying smart contract crafts a shipment contract. Once this agreement is in place, an appropriate logistics partner is chosen. All agreements and stipulations are meticulously recorded within an NFT, consented upon by all involved entities (i.e. vendor, consumer, logistics entity).

The physical shipment process, potentially involving multiple couriers, is orchestrated by the logistics company. Upon reaching the consumer and obtaining an affirmation of product integrity, the NFT records this validation. The final transactional phase sees the consumer settle any outstanding product payments, the logistics entity obtaining their fees and security deposits, and the vendor procuring the product sales revenue. Any discrepancies or contractual breaches get resolved based on the smart contract's predefined conditions, ensuring transparency and fairness.

In culmination, all transactions get appended to the distributed ledger, making them immutable and transparent, and the system resets, readying for the next shipment cycle.

## V. Implementation Process for Advanced Patient-Centric Medical Test Record Management

The core objective of our research paper is to leverage the innate capabilities of the blockchain, especially in the realm of Non-Fungible Tokens (NFTs), to provide a seamless experience for patients managing and sharing their medical test results. The very design of our proposed model, which emphasizes intuitive patient-centric management of test results, coupled with the ease of sharing these results with any desired entity, underscores the need to opt for EVM-enabled blockchain platforms, eschewing the Hyperledger ecosystem, to enable broader accessibility.

In this vein, our efforts have been directed towards discerning the most apt platform that can seamlessly host our model. Our search and subsequent evaluations led us to focus on four of the contemporary leading blockchain platforms, each supporting the Ethereum Virtual Machine (EVM) - Binance Smart Chain (BNB Smart Chain)[11], Polygon[12], Fantom[13], and Celo[14].

Our contributions to this domain have been further enriched by sharing the implementation details on these platforms, thus, fostering a transparent discourse around transaction costs asso-

---

[11] https://github.com/bnb-chain/whitepaper/blob/master/WHITEPAPER.md
[12] https://polygon.technology/lightpaper-polygon.pdf
[13] https://whitepaper.io/document/438/fantom-whitepaper
[14] https://celo.org/papers/whitepaper
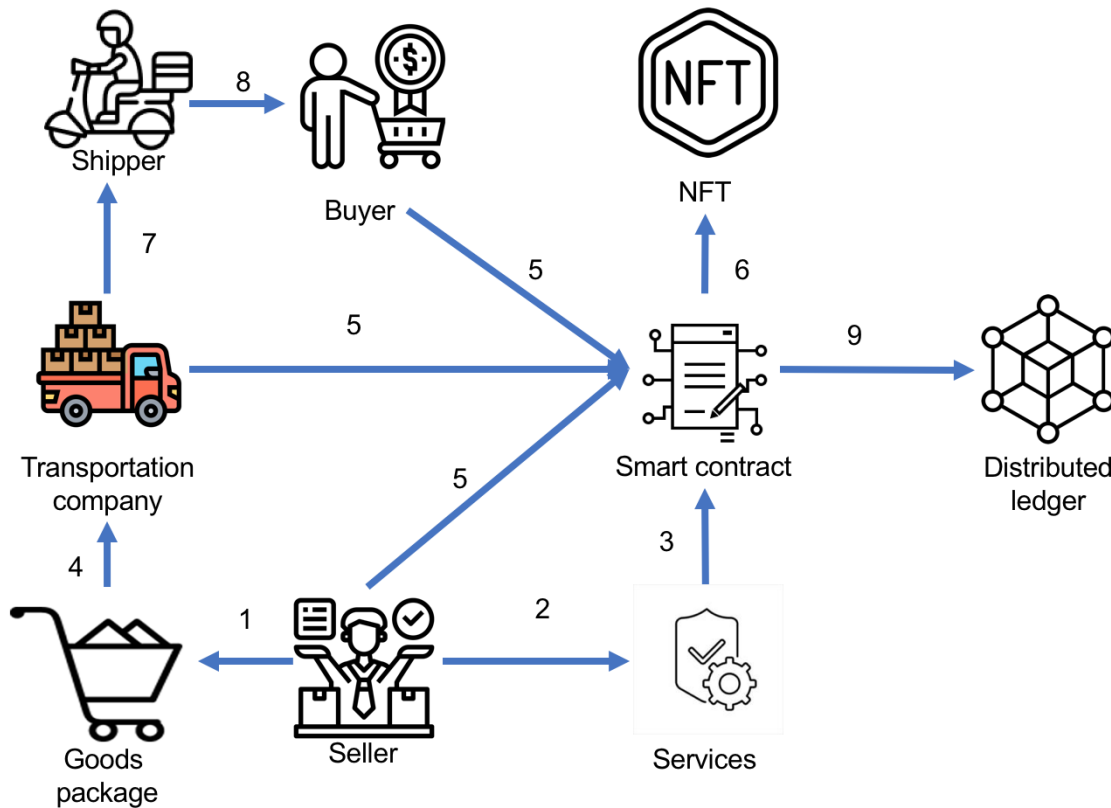
Fig. 3. Innovative freight model harnessing Blockchain, Smart Contracts, and NFTs.

ciated with these platforms' native tokens[15], namely, BNB[16], MATIC[17], FTM[18], and CELO[19].

The culmination of our assessments was directed towards ascertaining the cost-effectiveness of executing smart contracts, designed leveraging the Solidity language, on the testnet environments of these platforms. This would be instrumental in guiding our decision on the optimal platform for deployment.

### A. Deployment on EVM-compatible Platforms with a Spotlight on BNB

The blockchain realm, especially platforms compatible with the Ethereum Virtual Machine (EVM), offers versatility that serves a range of applications. In discussing a tripartite model involving sellers, shippers, and buyers and bolstered with an integrated consensus protocol for payments, the superiority of EVM-compatible platforms is evident.

This section provides an intricate look at our model's integration on these platforms, emphasizing its deployment on the Binance Smart Chain (BNB) - Fig. 4.

---

[15]Our models were released on 11/24/2022, 8:44:53 AM UTC

[16]https://testnet.bscscan.com/address/0xafa3888d1dfbfe957\
\b1cd68c36ede4991e104a53

[17]https://mumbai.polygonscan.com/address/
0xd9ee80d850ef3c4978dd0b099a45a559fd7c5ef4

[18]https://testnet.ftmscan.com/address/0x4a2573478c67a894e32d806\
\c8dd23ee8e26f7847

[19]https://explorer.celo.org/alfajores/address/
0x4a2573478C67a894E32D806c8Dd23EE8E26f7847/transactions



Fig. 4. Snapshot of transaction details, specifically from BNB smart chain.

This figure is a snapshot highlighting transaction details on the Binance Smart Chain (BNB). Within this image, users would observe an interface displaying transaction IDs, timestamps of transactions, sender and receiver addresses, and the amount transferred. Furthermore, it likely showcases the transaction's status (whether it's pending, failed, or successful), gas fees associated, and possibly even a link to the block where this transaction is recorded. By analyzing this snapshot, one can discern the efficiency and speed of transactions on the BNB Smart Chain and understand its user-friendly interface.

In Fig. 5, the visualization concentrates on the non-fungible token (NFT) creation process. This graphical representation likely delineates the steps involved in minting an NFT, from selecting the digital asset, inputting metadata, determining rarity or attributes, to finally issuing or minting it on the blockchain. The figure may also exhibit the interaction with smart contracts during the NFT creation and any gas fees or computational resources required. The graphical elements emphasize the uniqueness and immutable nature of NFTs and

Fig. 5. Visualization of the NFT creation process.

the efficiency of the BNB Smart Chain in facilitating their creation.



Fig. 6. Demonstration of NFT transfer mechanics.

The focus of Fig. 6 is on the intricacies of NFT transfers, especially concerning the ERC-721 token standard. This diagram likely presents an NFT's journey from one digital wallet to another, illustrating the security protocols, verification processes, and blockchain confirmations involved. An integral aspect might also include the interaction with the underlying ERC-721 smart contract, ensuring the asset's authenticity and ownership transfer. This figure aims to highlight the seamlessness and secure nature of transferring unique digital assets on platforms that adhere to the ERC-721 standard.

Continuing from earlier, our goal is to benchmark our system against four premier EVM-compatible platforms. By sharing our insights on these platforms, we aim to enlighten the community and gather actionable data. Through a meticulous analysis of smart contract execution costs in these testnet environments, we seek the platform that blends optimal cost-efficiency with performance for tangible deployments.

Our implementation model focuses on two main purposes i) data manipulation (i.e. package) - initialization, query and update - on blockchain platform and ii) generation of NFTs for each order goods for easy retrieval by sellers and buyers (i.e. product reviews before and after delivery).

### B. Data and NFT Initialization Procedure

The intricacies of initializing package data, from its inception to the eventual registration on the blockchain, are portrayed in Figure 7. This diagram offers an overview of the process and helps comprehend the significance of each step.

Package data is a conglomerate of multiple parameters:

- Sender's Details: This pertains to the individual or entity dispatching the goods. It includes crucial aspects such as the sender's address, the weight of the package, and specifics about the item being sent.

- Recipient's Details: It's essential to ascertain where the package is headed. Data includes the recipient's address and an estimated time of arrival.

- Security Deposits: The financial security mechanisms are indispensable in maintaining the integrity of the system. Each of the three key participants - sender, recipient, and shipper - deposits an amount that acts as a safeguard, facilitating automatic resolution of potential disputes via the smart contract.

- Metadata of the Package: Further granular details about the package are recorded, such as which shipping company is responsible, when and where it's to be delivered or picked up, etc. This becomes exceedingly crucial in scenarios involving multiple shippers, which could either belong to the same logistics company or different entities.

To fortify data consistency and system efficiency, the platform employs a distributed ledger model. This supports concurrent storage, mimicking a peer-to-peer network structure, enabling multiple users to store data simultaneously, thereby diminishing system latency.

The structure of package data can be understood by examining the following data representation:

```
goodsObject = {
"goodsID": goodsID,
"deliveryCompanyID": deliveryCompanyID,
"shipperID": shipperID,
"type": type of goods,
"buyerID": buyerID,
"sellerID": sellerID,
"quantity": quantity,
"unit": unit,
"packageID": packageID,
"addressReceived": received address,
"addressDelivery": delivery address,
"time": time,
"location": location,
"state": Null
};
```

Within this structure:

- The "state" parameter is a dynamic attribute, commencing as a Null value. A change to 1 signifies the shipping company has taken possession of the goods, whereas a 0 implies it's awaiting collection by the shipper.

- The "unit" denotes the order's quantity. An adjunct "packageID" helps in tracking the particular package associated with the order.

Post the collection of packages from sellers, the onus falls on shippers to ensure the items are consistent with the listed details. Post verification, they're held in a temporary digital storage before getting committed to the blockchain.

The verification process is paramount, for any discrepancies or damages can directly impact the shipping procedure. Furthermore, it establishes a foundation for resolving conflicts that might arise during the transportation of goods.
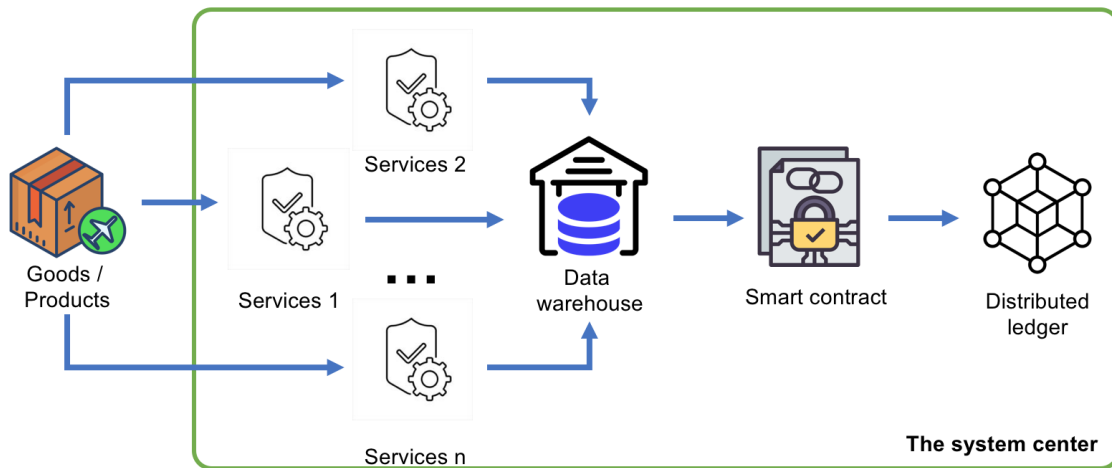
Fig. 7. Procedure to initialize data and NFT for goods.

NFTs, in this context, encapsulate distinct attributes of each order. Beyond the conventional details, they also record financial commitments in the form of deposits from each party involved. The NFT structure is as such:

```
NFT PACKAGE = {
"shipperID": shipperID,
"sellerID": sellerID,
"buyerID": buyerID,
"packageID": packageID,
"type": type of goods,
"quantity": quantity,
"addressReceived": received address,
"addressDelivery": delivery address,
"depositShipper": deposit of shipper,
"depositSeller": deposit of seller,
"depositBuyer": deposit of buyer,
"time": estimated delivery time
};
```

NFTs offer a transparent mechanism to track goods and ensure accountability. For instance, in cases of delivery delays, the embedded information within the NFT provides a clear path for conflict resolution.

For more nuanced interpretations of stakeholder deposits and related topics, our preceding research works and articles offer a comprehensive discussion.

### C. In-depth Examination of Data Query Process

The data query process, depicted in Fig. 8, is as intricate as the data initialization phase, and its operations are molded to accommodate multiple simultaneous participants. The overarching principle is the distributed model, which caters to an environment where several users can query data concurrently, ensuring the system's scalability and flexibility.

Different stakeholders have distinct query requirements:

1) Shippers: Their primary focus is on logistical details. They query data to obtain specifics like the
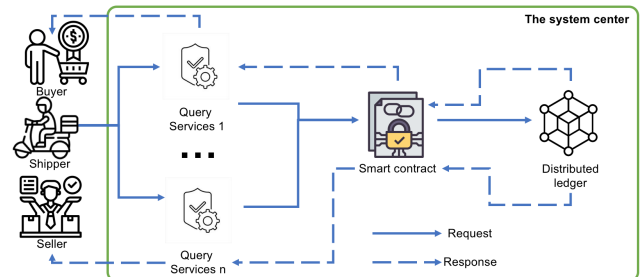


Fig. 8. Illustration of the data query process.

consignee's particulars and their corresponding addresses. Such information is pivotal to ensure the seamless delivery of goods to the right destinations.

2) Sellers/Buyers: Their queries are more customer-centric. Sellers and buyers are keen on tracking the status of their orders, particularly post-dispatch and receipt. Furthermore, if any discrepancies or issues arise—be it delays or damages—they would resort to this system to glean insights and possibly initiate conflict resolution processes.

The data retrieval mechanism can be delineated as follows:

- Users, be it shippers or sellers/buyers, initiate their query through a predefined service, often implemented as an API call. These calls are essentially instructions directed at smart contracts present in the blockchain system. Each smart contract has specific functions tailored to handle a variety of tasks, and in this context, it deals with fetching the requisite data from the distributed ledger.

- Every query isn't just a fleeting transaction; it's logged within the system. This implies that all retrieval requests metamorphose into a query history, which is associated with the respective individual or organization. Such a chronicle can be instrumental for audit trails or to understand behavioral patterns of users over time.

A point of intrigue in this system is the handling of more complex shipping processes. When a package's journey isn't a straightforward 'A to B' route, but rather involves multiple intermediary stops with various shippers handling the goods, the complexity grows. In such multi-hop scenarios, where several shippers—either from the same or different logistics companies—are involved, NFTs play a crucial role. They act as verifiable digital tokens at each handover point, ensuring transparency and traceability.

However, the system is designed to be robust but not infallible. Instances might arise where queries return no results, possibly due to erroneous inputs like an incorrect ID. In such scenarios, the system is intuitive enough to relay a 'not found' message, ensuring users are promptly informed.

Lastly, when it comes to NFT-based queries, they are seamlessly integrated with the overarching system. All necessary services to handle NFT inquiries are provided as APIs, facilitating easy and efficient interactions for users.

### D. An In-depth Exploration of the Data Update Mechanism
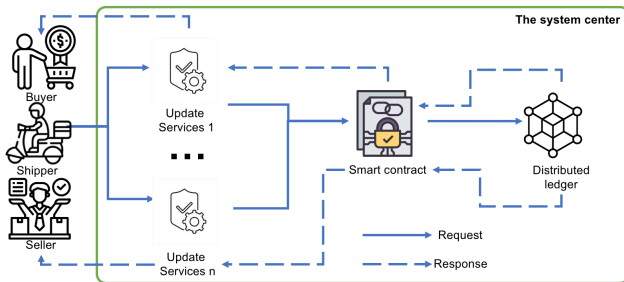


Fig. 9. Illustration of the data update mechanism.

Updating data within the blockchain requires utmost precision, given the immutability of records once entered. This process is not simply about making amendments; it's about ensuring the integrity of the entire system.

Before any data can be updated, there's a prerequisite: the data in question must exist. This might sound simple, but it's a crucial step. This is ensured by invoking the data query procedure beforehand. In simpler terms, before attempting any changes, the system checks if the data entry to be updated is actually present. If it isn't, the user is promptly notified with a message, as detailed in the previous Section V-C.

The architecture to support data updates is structured and methodical:

- API Integration: Similar to the mechanisms for data querying and initialization, the update services are provided through APIs. These Application Programming Interfaces act as gateways. They allow users to submit their update requests, which are then funneled to the appropriate part of the system for further action.

- Smart Contract Interaction: Once the API receives an update request, it communicates with a designated smart contract. Smart contracts are like automated intermediaries, each with specific functions to ensure that the processes within the blockchain are executed

correctly. In this context, the smart contract handles the updating of data based on the request received.

- Purpose and Implications: The main objective of the update process is multifaceted. One primary role is to track and record the evolving status of packages as they move through various transit points. But it goes beyond mere tracking; it also addresses anomalies or issues. If something isn't right - maybe there's damage, or a package goes missing - the system can initiate conflict resolution mechanisms. This is achieved through a combination of smart contract logic and the attributes of Non-Fungible Tokens (NFTs).

Fig. 9 offers a visual representation of this intricate dance of data updates. When it comes to the realm of NFTs, the update dynamics take a slightly different hue. An NFT, by its very nature, is unique and cannot be replicated. Therefore, updating an NFT doesn't mean modifying its existing attributes. Instead, when details associated with an NFT need to be changed, the system creates a brand-new NFT to capture those updates. On the surface, this might seem like a mere transfer, like moving an NFT from one owner's address to another. But underneath, it ensures the veracity and traceability of each unique digital asset, as further explained in subsection V-B.

## VI. IN-DEPTH EVALUATION OF CONTRACT OPERATIONS

In our thorough evaluation, we scrutinize the intricacies of the expenses tied to blockchain operations, such as contract creation, NFT generation, and the dynamic transfer or retrieval of NFTs. These operations, illustrated in Fig. 5 and 6, bring with them costs. We categorize these costs under four main subsections: i) Transaction Fee; ii) Gas limit; iii) Gas Used by Transaction; and iv) Gas Price. Each of these sections offers a lens into the underlying costs and efficiencies of the blockchain processes.

Blockchain operations are often lauded for their immutable record-keeping and decentralized nature, but it's equally essential to understand the associated costs. Contract creation, NFT generation, and transfer each have their own set of expenses. These costs ensure the sustainability of the network, compensate for the computational effort, and can also act as a deterrent against frivolous or malicious activities. A closer examination of these costs can offer insights into the economic viability of blockchain-based systems.

### A. Transaction Fee Analysis

The transaction fee is a fundamental aspect of our evaluation. It acts as a "price" for the computational and operational services provided by the blockchain. To showcase the relative costs across various platforms, we present a detailed breakdown in Table I.

From Table I, we can infer a few pivotal insights:

- Variability across Chains: There's a noticeable difference in transaction fees across different chains. For instance, the BNB Smart Chain's contract creation is significantly higher than that of Fantom or Polygon. Such variations can be attributed to the underlying architecture, consensus mechanism, network congestion, and other chain-specific factors.

TABLE I. TRANSACTION FEE

|  | Contract Creation | Create NFT | Transfer NFT |
|---|---|---|---|
| BNB Smart Chain | 0.02731184 BNB ($8.32) | 0.00109162 BNB ($0.33) | 0.00057003 BNB ($0.17) |
| Fantom | 0.009576994 FTM ($0.001850) | 0.0002405167 FTM ($0.000078) | 0.0002380105 FTM ($0.000046) |
| Polygon | 0.006840710032835408 MATIC($0.01) | 0.0002894050001852192 MATIC($0.00) | 0.000170007501088048 MATIC($0.00) |
| Celo | 0.0070974384 CELO ($0.004 ) | 0.0002840812 CELO ($0.000 ) | 0.0001554878 CELO ($0.000 ) |

- Cost Gradient in Operations: Contract creation typically incurs a higher fee than other operations across all chains. This indicates the relative computational complexity and resources utilized during this process.

- Micro-transactions: Some fees, especially on chains like Polygon and Fantom, are incredibly minute, hinting at their potential suitability for high-frequency, low-value transactions.

Understanding these nuances is crucial for both developers and users, as it helps in making informed decisions about which chain to use, especially when balancing between operational costs and performance requirements.

### B. Diving into Gas Limit Values

Gas limit refers to the maximum amount of units of gas the sender is willing to spend on a transaction or contract execution. It is a protective mechanism to ensure that a process doesn't run indefinitely, especially if something goes wrong. The Table II provides a clear breakdown of the gas limits set for three distinct operations across four blockchain platforms.

Table II distinguishes the gas limit values for three types of operations: Contract Creation, NFT Creation, and NFT Transfer across the BNB Smart Chain, Fantom, Polygon, and Celo blockchain platforms.

**Detailed Insights**:

BNB Smart Chain:

- The gas limit for contract creation stands at 2,731,184.

- For creating an NFT, the gas limit is considerably lower at 109,162.

- Interestingly, transferring an NFT requires a higher gas limit of 3,000,000, which is the highest among the three operations on this chain.

Fantom & Polygon:

- Both Fantom and Polygon have identical gas limits for the operations showcased.

- Contract creation requires a gas limit of 2,736,284.

- Creating an NFT comes in at 115,762.

- Transferring an NFT consumes the least gas limit, set at 72,803.

Celo:

- Celo has a distinctively higher gas limit for contract creation, which is 3,548,719, making it the highest among the platforms presented.

- The gas limit for NFT creation is 142,040.

- NFT transfer operations require 85,673 as the gas limit, which, similar to the trend in Fantom and Polygon, is less than the gas limit for NFT creation.

**General Observations**:

- Comparative Gas Limits: Across platforms, the gas limit for contract creation is consistently higher than that of creating an NFT, indicating the relative complexity of the contract creation process.

- NFT Transfers: The gas limits for NFT transfers differ significantly between chains. For instance, on the BNB Smart Chain, the limit is exceptionally high, whereas, on Fantom and Polygon, it's much lower. This suggests varying computational demands and efficiencies in the transfer process across these platforms

- Consistency between Fantom and Polygon: The identical gas limits for Fantom and Polygon for all three operations might indicate similarities in their underlying architecture or processing mechanisms for these specific operations.

In general, understanding the gas limit is essential for blockchain developers and users as it provides insights into transactional and operational costs. The values in Table II offer a comparative view of the efficiency and computational demands of different operations across various blockchain platforms.

### C. Insight into Gas Consumption

Table III provides a comprehensive analysis of the gas utilized for various operations across four blockchain platforms. Unlike the gas limit which signifies the maximum gas units that could potentially be spent, "Gas Used by Transaction" indicates the actual gas consumed by an operation, thus giving a clearer picture of efficiency.

Table III showcases the gas consumed in units and as a percentage of the gas limit for three main operations: Contract Creation, NFT Creation, and NFT Transfer. These operations are evaluated across BNB Smart Chain, Fantom, Polygon, and Celo blockchain platforms.

**Detailed Breakdown:**

BNB Smart Chain:

- The contract creation operation uses all its gas limit, consuming 2,731,184 units, which equates to 100% utilization.

- Creating an NFT also exhausts its set gas limit, utilizing 109,162 units or 100

TABLE II. GAS LIMIT

|  | Contract Creation | Create NFT | Transfer NFT |
|---|---|---|---|
| BNB Smart Chain | 2,731,184 | 109,162 | 3,000,000 |
| Fantom | 2,736,284 | 115,762 | 72,803 |
| Polygon | 2,736,284 | 115,762 | 72,803 |
| Celo | 3,548,719 | 142,040 | 85,673 |

TABLE III. GAS USED BY TRANSACTION

|  | Contract Creation | Create NFT | Transfer NFT |
|---|---|---|---|
| BNB Smart Chain | 2,731,184 (100%) | 109,162 (100%) | 57,003 (1.9%) |
| Fantom | 2,736,284 (100%) | 115,762 (100%) | 68,003 (93.41%) |
| Polygon | 2,736,284 (100%) | 115,762 (100%) | 68,003 (93.41%) |
| Celo | 2,729,784 (76.92%) | 109,262 (76.92%) | 59,803 (69.8%) |

- In contrast, NFT transfer is highly efficient, consuming only 57,003 units, which is just 1.9% of its gas limit.

Fantom & Polygon:

- Both Fantom and Polygon have matching gas utilization statistics.

- Contract creation and NFT creation operations use up their entire gas limit, consuming 2,736,284 and 115,762 units respectively, which translates to 100% utilization for both.

- The NFT transfer operation, however, uses 68,003 units, or 93.41% of its gas limit, indicating a high efficiency but not as optimal as the previous two operations.

Celo:

- For contract creation, 2,729,784 units of gas are used, translating to 76.92% utilization of its gas limit.

- Creating an NFT follows the same pattern with 109,262 units consumed, equating to 76.92

- The NFT transfer operation on Celo uses 59,803 units, or 69.8% of its allocated gas limit.

**Observations:**

- Full Utilization on BNB Smart Chain, Fantom, and Polygon: For the operations of contract creation and NFT creation, both the BNB Smart Chain and Fantom-Polygon duo show a 100% gas utilization, indicating that these operations are maximally optimized or perhaps the gas limits set are just adequate for these operations.

- Diversity in NFT Transfer Efficiency: The efficiency of the NFT transfer operation varies significantly across platforms. BNB Smart Chain is highly efficient, utilizing only a small fraction of its gas limit, while Fantom and Polygon use over 90%. Celo falls in between, using just under 70%.

- Celo's Consistent Utilization Pattern: Celo displays a consistent pattern of gas consumption across the operations, with both contract and NFT creation operations having identical utilization percentages. This

could hint at a standard optimization mechanism or architectural decision inherent to the Celo platform.

In essence, Table III offers an in-depth perspective on the operational efficiency of various tasks across different blockchains. Such insights are invaluable for developers and users to understand the performance and optimization levels of each platform for specific operations.

### D. Gas Price Analysis Across Blockchain Platforms

Table IV delves into the nuances of gas prices associated with specific blockchain transactions. Gas prices are critical as they are the cost per unit of gas, and thus dictate the transaction fee users will pay for their actions on a given blockchain network. By understanding these prices, users can gauge the economic feasibility of their operations on each platform. This table enumerates the gas prices for three primary blockchain operations: Contract Creation, NFT Creation, and NFT Transfer. These prices are examined across four prominent blockchain platforms: BNB Smart Chain, Fantom, Polygon, and Celo.

- BNB Smart Chain: Across all three operations, the gas price remains consistent at 0.00000001 BNB, equivalent to 10 Gwei. This uniformity suggests a standardized price point for transactions on this platform, regardless of the operation's nature.

- Fantom: Fantom too demonstrates a steady gas price for all operations at 0.0000000035 FTM, equating to 3.5 Gwei. This price is lower than BNB Smart Chain, hinting at more economical transactions on the Fantom network.

- Polygon: Polygon's gas prices for each operation are consistent at the microscopic level of 0.000000002500000012 MATIC and 0.000000002500000016 MATIC, which translate to 2.500000012 Gwei and 2.500000016 Gwei, respectively. While there are slight variations in the gas price between the operations, they are marginal and may result from intricate calculations or rounding mechanisms inherent to the Polygon platform.

- Celo: Celo's gas prices for all three operations are set at 0.0000000026 CELO. These prices correlate with a Max Fee per Gas of 2.7 Gwei. The "Max Fee per Gas" metric in Celo might indicate a pricing cap or standard set by the platform to ensure price stability.

TABLE IV. GAS PRICE

| | Contract Creation | Create NFT | Transfer NFT |
|---|---|---|---|
| BNB Smart Chain | 0.00000001 BNB (10 Gwei) | 0.00000001 BNB (10 Gwei) | 0.00000001 BNB (10 Gwei) |
| Fantom | 0.0000000035 FTM (3.5 Gwei) | 0.0000000035 FTM (3.5 Gwei) | 0.0000000035 FTM (3.5 Gwei) |
| Polygon | 0.000000002500000012 MATIC (2.500000012 Gwei) | 0.000000002500000016 MATIC (2.500000016 Gwei) | 0.000000002500000016 MATIC (2.500000016 Gwei) |
| Celo | 0.0000000026 CELO (Max Fee per Gas: 2.7 Gwei) | 0.0000000026 CELO (Max Fee per Gas: 2.7 Gwei) | 0.0000000026 CELO (Max Fee per Gas: 2.7 Gwei) |

**Insights:**

- Uniformity Across Platforms: Both BNB Smart Chain and Fantom showcase a uniform gas price across all operations, while Polygon and Celo exhibit minimal variations. Such consistency can help users predict their transaction costs with higher accuracy.

- Comparative Economy: When juxtaposing the platforms, Fantom and Polygon present themselves as the more economical options, with gas prices lower than BNB Smart Chain. Celo, while being slightly higher than Polygon, still offers a competitive rate, especially when compared to BNB Smart Chain.

- Gwei Representation: Representing gas prices in Gwei offers a standardized lens to compare across blockchains. Gwei is a common denomination used in the context of Ethereum-based blockchains, making it a familiar reference point for many users.

In conclusion, Table IV serves as a valuable resource for users to understand and compare the financial implications of their actions on different blockchain platforms. By staying informed on these gas prices, users can make more informed decisions about where and when to transact.

## VII. DISCUSSION

### A. Threats to Validity

Our study, while comprehensive in its approach, acknowledges potential threats to its validity. One prominent challenge is the dynamic nature of gas prices. They are known to fluctuate based on network congestion, overall demand, and blockchain-specific factors, meaning our analysis, which captures a specific moment in time, might not remain representative in the future. Furthermore, each blockchain platform has its unique mechanisms, such as gas auctions, that can introduce variations in gas prices and potentially lead to disparities in the actual transaction costs. External economic factors also play a pivotal role. The volatile nature of cryptocurrency valuations means the conversion of gas prices to traditional currency can vary greatly, impacting the real-world perception of operational costs. Lastly, our findings focus on a select group of operations and platforms, raising questions about the generalizability of our conclusions to other operations or nascent blockchain platforms.

### B. Observations and Findings

Several key observations emerge from our analysis. Platforms like the BNB Smart Chain and Fantom exhibit a remarkable uniformity in their pricing structure across operations, which could potentially simplify cost predictions for users.

There's also an evident economic disparity between platforms. For instance, when observing gas prices, Fantom and Polygon present themselves as more economical choices compared to the BNB Smart Chain. Notably, the consistent use of Gwei as a unit for expressing gas prices provides a standard frame of reference, which aids in drawing comparative conclusions across diverse blockchains.

### C. Future Work

The future direction of our research aims to address some of the identified limitations and expand the horizons of our current findings. A temporal analysis could be beneficial, wherein tracking gas prices over extended periods might help identify patterns like peak congestion periods or times conducive to economical transactions. As the blockchain ecosystem grows, incorporating newer platforms into our analysis can offer a holistic view of the evolving landscape. A deeper dive into the economic models driving each blockchain platform might provide clarity on the reasons behind the observed gas prices. Furthermore, examining user behavior in response to fluctuating gas prices can offer invaluable insights into transaction patterns, platform preferences, and challenges hindering blockchain adoption.

The delineation of our subsequent directions in research is pivotal for contextual understanding. We are inclined to delve deeper into the introduction of *intricate methods and algorithms*, specifically those related to encryption and decryption. Such operations, foundational to preserving data integrity and security in blockchain platforms, offer a paradigm to examine the pecuniary ramifications of safeguarding transactional data on the blockchain [27], [28]. Parallel to this, the exploration of *complex data structures* presents a unique lens, offering insights into the interplay between data intricacies and transactional efficiency. The impetus to deploy our proposed model in a tangible, operational realm is palpable. The very act of *transposing our recommendation system onto the FTM mainnet* would be a leap from a sandboxed environment to a live ecosystem pulsating with real transactions. A discernible lacuna in our present analysis is our oversight of the multifaceted dimensions of user privacy policies. With citations underscoring the imperatives of access control and dynamic policy [29], [30], [31], [32], we're inclined to probe the nuances of how these privacy constructs shape transaction costs. Future vistas beckon us towards a slew of *infrastructure-centric methodologies*. The confluence of modernist paradigms like gRPC [33], [34], Microservices [35], [36], adaptive messaging systems, and broker-less architectures [37] presents a promising trajectory. A pivot towards an *API-call-centric* interface may very well be the linchpin, bridging users with a system that seamlessly obfuscates its underlying complexities while offering a user-centric experience.

## VIII. CONCLUSION

Motivated by the pressing need to bridge this gap, our research ventured into the realm of NFTs, harnessing their potential to encapsulate package specifics. Our multi-pronged approach aimed at architecting a robust shipping paradigm anchored in blockchain, enriched with the finesse of smart contracts, and enhanced by NFTs. The meticulous design and deployment of NFT-empowered smart contracts have laid the groundwork for transparent, accountable, and seamless interactions among all stakeholders, including shippers. Our empirical assessment, spanning several leading EVM platforms, not only corroborates the viability of our proposed model but also underscores the transformative potential it holds for reshaping the shipping and logistics sector.

In conclusion, while blockchain technology and smart contracts herald a promising dawn, the path to holistic and inclusive transactional frameworks demands continuous innovation and introspection. Our endeavor stands testament to this, striving to chart a course where trust is not merely assumed but systematically engineered.

## ACKNOWLEDGMENT

## REFERENCES

[1] Y. Madhwal, Y. Borbon-Galvez, N. Etemadi, Y. Yanovich, and A. Creazza, "Proof of delivery smart contract for performance measurements," *IEEE Access*, vol. 10, pp. 69 147–69 159, 2022.

[2] S. Nakamoto, "Bitcoin: A peer-to-peer electronic cash system," *Decentralized Business Review*, p. 21260, 2008.

[3] D. Sinha and S. R. Chowdhury, "Blockchain-based smart contract for international business–a framework," *Journal of Global Operations and Strategic Sourcing*, 2021.

[4] V. Buterin *et al.*, "A next-generation smart contract and decentralized application platform," *white paper*, vol. 3, no. 37, pp. 2–1, 2014.

[5] H. X. Son *et al.*, "Towards a mechanism for protecting seller's interest of cash on delivery by using smart contract in hyperledger," *International Journal of Advanced Computer Science and Applications*, vol. 10, no. 4, pp. 45–50, 2019.

[6] M. A. Uddin, A. Stranieri, I. Gondal, and V. Balasubramanian, "A survey on the adoption of blockchain in iot: Challenges and solutions," *Blockchain: Research and Applications*, vol. 2, no. 2, p. 100006, 2021.

[7] E. Androulaki, A. Barger, V. Bortnikov, C. Cachin, K. Christidis, A. De Caro, D. Enyeart, C. Ferris, G. Laventman, Y. Manevich *et al.*, "Hyperledger fabric: a distributed operating system for permissioned blockchains," in *Proceedings of the thirteenth EuroSys conference*, 2018, pp. 1–15.

[8] S. Shi, D. He, L. Li, N. Kumar, M. K. Khan, and K.-K. R. Choo, "Applications of blockchain in ensuring the security and privacy of electronic health record systems: A survey," *Computers & security*, vol. 97, p. 101966, 2020.

[9] Z. Zheng, S. Xie, H.-N. Dai, W. Chen, X. Chen, J. Weng, and M. Imran, "An overview on smart contracts: Challenges, advances and platforms," *Future Generation Computer Systems*, vol. 105, pp. 475–491, 2020.

[10] X. S. Ha, T. H. Le, T. T. Phan, H. H. D. Nguyen, H. K. Vo, and N. Duong-Trung, "Scrutinizing trust and transparency in cash on delivery systems," in *International Conference on Security, Privacy and Anonymity in Computation, Communication and Storage*. Springer, 2020, pp. 214–227.

[11] N. T. T. Le *et al.*, "Assuring non-fraudulent transactions in cash on delivery by introducing double smart contracts," *International Journal of Advanced Computer Science and Applications*, vol. 10, no. 5, pp. 677–684, 2019.

[12] K. L. Quoc, H. K. Vo, L. H. Huong, K. H. Gia, K. T. Dang, H. L. Van, N. H. Huu, T. N. Huyen, L. Van Cao Phu, D. N. T. Quoc *et al.*, "Sssb: An approach to insurance for cross-border exchange by using smart contracts," in *International Conference on Mobile Web and Intelligent Information Systems*. Springer, 2022, pp. 179–192.

[13] X. S. Ha, H. T. Le, N. Metoui, and N. Duong-Trung, "Dem-cod: Novel access-control-based cash on delivery mechanism for decentralized marketplace," in *2020 IEEE 19th International Conference on Trust, Security and Privacy in Computing and Communications (TrustCom)*. IEEE, 2020, pp. 71–78.

[14] H. T. Le, N. T. T. Le, N. N. Phien, and N. Duong-Trung, "Introducing multi shippers mechanism for decentralized cash on delivery system," *International Journal of Advanced Computer Science and Applications*, vol. 10, no. 6, 2019.

[15] N. Duong-Trung, H. X. Son, H. T. Le, and T. T. Phan, "On components of a patient-centered healthcare system using smart contract," in *Proceedings of the 2020 4th International Conference on Cryptography, Security and Privacy*, 2020, p. 31–35.

[16] ——, "Smart care: Integrating blockchain technology into the design of patient-centered healthcare systems," in *Proceedings of the 2020 4th International Conference on Cryptography, Security and Privacy*, ser. ICCSP 2020, 2020, p. 105–109.

[17] N. T. T. Quynh, H. X. Son, T. H. Le, H. N. D. Huy, K. H. Vo, H. H. Luong, K. N. H. Tuan, T. D. Anh, N. Duong-Trung *et al.*, "Toward a design of blood donation management by blockchain technologies," in *International Conference on Computational Science and Its Applications*. Springer, 2021, pp. 78–90.

[18] H. T. Le, T. T. L. Nguyen, T. A. Nguyen, X. S. Ha, and N. Duong-Trung, "Bloodchain: A blood donation network managed by blockchain technologies," *Network*, vol. 2, no. 1, pp. 21–35, 2022.

[19] H. T. Le, L. N. T. Thanh, H. K. Vo, H. H. Luong, K. N. H. Tuan, T. D. Anh, K. H. N. Vuong, H. X. Son *et al.*, "Patient-chain: Patient-centered healthcare system a blockchain-based technology in dealing with emergencies," in *International Conference on Parallel and Distributed Computing: Applications and Technologies*. Springer, 2022, pp. 576–583.

[20] S. Nakamoto, "Bitcoin: A peer-to-peer electronic cash system bitcoin: A peer-to-peer electronic cash system," *Bitcoin. org. Disponible en https://bitcoin. org/en/bitcoin-paper*, 2009.

[21] G. Shang, N. Ilk, and S. Fan, "Need for speed, but how much does it cost? unpacking the fee-speed relationship in bitcoin transactions," *Journal of Operations Management*, 2022.

[22] Ethereum, "How our escrow smart contract works," 2022. [Online]. Available: https://www.thenational.ae/business/technology/cash-on-delivery-the-biggest-obstacle-\to-e-commerce-in-uae-and-region-1

[23] OpenBazaar, "Truly decentralized, peer-to-peer ecommerce features," 2022. [Online]. Available: https://openbazaar.org/features/

[24] N. Duong-Trung *et al.*, "Multi-sessions mechanism for decentralized cash on delivery system," *International Journal of Advanced Computer Science and Applications*, vol. 10, no. 9, 2020.

[25] "Two party contracts," 2022. [Online]. Available: https://dappsforbeginners.wordpress.com/tutorials/two-party-contracts/

[26] G. D. Marzo, F. Pandolfelli, and V. D. Servedio, "Modeling innovation in the cryptocurrency ecosystem," *Scientific Reports*, vol. 12, no. 1, pp. 1–12, 2022.

[27] H. X. Son, M. H. Nguyen, H. K. Vo *et al.*, "Toward an privacy protection based on access control model in hybrid cloud for healthcare systems," in *International Joint Conference: 12th International Conference on Computational Intelligence in Security for Information Systems (CISIS 2019) and 10th International Conference on EUropean Transnational Education (ICEUTE 2019)*. Springer, 2019, pp. 77–86.

[28] H. X. Son and N. M. Hoang, "A novel attribute-based access control system for fine-grained privacy protection," in *Proceedings of the 3rd International Conference on Cryptography, Security and Privacy*, 2019, pp. 76–80.

[29] S. H. Xuan *et al.*, "Rew-xac: an approach to rewriting request for elastic abac enforcement with dynamic policies," in *2016 International Conference on Advanced Computing and Applications (ACOMP)*.   IEEE, 2016, pp. 25–31.

[30] H. X. Son, T. K. Dang, and F. Massacci, "Rew-smt: a new approach for rewriting xacml request with dynamic big data security policies," in *International Conference on Security, Privacy and Anonymity in Computation, Communication and Storage*.   Springer, 2017, pp. 501–515.

[31] Q. N. T. Thi, T. K. Dang, H. L. Van, and H. X. Son, "Using json to specify privacy preserving-enabled attribute-based access control policies," in *International Conference on Security, Privacy and Anonymity in Computation, Communication and Storage*.   Springer, 2017, pp. 561–570.

[32] N. M. Hoang and H. X. Son, "A dynamic solution for fine-grained policy conflict resolution," in *Proceedings of the 3rd International Conference on Cryptography, Security and Privacy*, 2019, pp. 116–120.

[33] L. T. T. Nguyen *et al.*, "Bmdd: a novel approach for iot platform (broker-less and microservice architecture, decentralized identity, and dynamic transmission messages)," *PeerJ Computer Science*, vol. 8, p. e950, 2022.

[34] L. N. T. Thanh *et al.*, "Toward a security iot platform with high rate transmission and low energy consumption," in *International Conference on Computational Science and its Applications*.   Springer, 2021.

[35] ——, "Toward a unique iot network via single sign-on protocol and message queue," in *International Conference on Computer Information Systems and Industrial Management*.   Springer, 2021.

[36] L. N. T. Thanh, N. N. Phien, T. A. Nguyen, H. K. Vo, H. H. Luong, T. D. Anh, K. N. H. Tuan, and H. X. Son, "Ioht-mba: An internet of healthcare things (ioht) platform based on microservice and brokerless architecture," *International Journal of Advanced Computer Science and Applications*, vol. 12, no. 7, 2021. [Online]. Available: http://dx.doi.org/10.14569/IJACSA.2021.0120768

[37] L. N. T. Thanh *et al.*, "Sip-mba: A secure iot platform with brokerless and micro-service architecture," *International Journal of Advanced Computer Science and Applications*, 2021.

# Recognition of Human Interactions in Still Images using AdaptiveDRNet with Multi-level Attention

Arnab Dey[1], Samit Biswas[2], Dac-Nhoung Le[3]

Computer Science and Technology,
Indian Institute of Engineering Science and Technology, Shibpur, Howrah, 711103, India[1, 2]
Faculty of Information Technology, Haiphong University, Haiphong, 180000, Vietnam[3]

*Abstract*—Human-Human Interaction Recognition (H2HIR) is a multidisciplinary field that combines computer vision, deep learning, and psychology. Its primary objective is to decode and understand the intricacies of human-human interactions. H2HIR holds significant importance across various domains as it enables machines to perceive, comprehend, and respond to human social behaviors, gestures, and communication patterns. This study aims to identify human-human interactions from just one frame, i.e. from an image. Diverging from the realm of video-based interaction recognition, a well-established research domain that relies on the utilization of spatio-temporal information, the complexity of the task escalates significantly when dealing with still images due to the absence of these intrinsic spatio-temporal features. This research introduces a novel deep learning model called AdaptiveDRNet with Multi-level Attention to recognize Human-Human (H2H) interactions. Our proposed method demonstrates outstanding performance on the Human-Human Interaction Image dataset (H2HID), encompassing 4049 meticulously curated images representing fifteen distinct human interactions and on the publicly accessible HII and HIIv2 related benchmark datasets. Notably, our proposed model excels with a validation accuracy of 97.20% in the classification of human-human interaction images, surpassing the performance of EfficientNet, InceptionResNetV2, NASNet Mobile, ConvXNet, ResNet50, and VGG-16 models. H2H interaction recognition's significance lies in its capacity to enhance communication, improve decision-making, and ultimately contribute to the well-being and efficiency of individuals and society as a whole.

*Keywords*—*Human interaction recognition; still images; adaptiveDRNet; multi level attention; human interactions*

## I. INTRODUCTION

Human-human interactions are the fundamental building blocks of human society, influencing various aspects of our lives, from personal relationships to collaborative efforts in professional settings. The study of these interactions has garnered increasing attention in recent years, driven by advancements in social psychology [1], communication sciences, and technology. Human-human interaction recognition from still images using deep learning has emerged as a compelling and cutting-edge research area with profound implications for a wide range of applications. In an era characterized by the ubiquity of image data and the growing demand for automated systems capable of understanding human behaviors, this field stands at the forefront of technological innovation.

In real-life scenarios, deep learning-based frameworks for recognizing human interactions in still images [2] find application in diverse fields. They play a crucial role in social

behavior analysis [3] by detecting and deciphering subtle cues in body language and gestures, facilitating a deeper understanding of human interactions. They also find utility in educational settings, specifically identifying classroom interactions. Analyzing human interactions yields valuable behavioral data, facilitating data-driven decision-making across diverse industries. Enabling systems to understand user behavior and intentions through images can create more intuitive interfaces across applications, from gaming to virtual reality, seamlessly adapting technology to human interaction and preferences. Furthermore, these frameworks assist in automated content tagging on social media and content-sharing platforms, enhancing content discoverability.

The proposed AdaptiveDRNet with Multi-level Attention model represents a significant advancement in human interaction recognition from still images, standing out for its distinctive architectural features. The proposed network combines the multi-level attention mechanism and an adaptive deep residual network to enhance its ability to recognize human-human interactions in images. The term "Adaptive" signifies the model's dynamic ability to adjust its focus and attention within the input data. This adaptiveness is facilitated by the Multi-level self-attention mechanism that allows the model to intelligently prioritize important information, enhancing its capacity to discern complex human interactions. Instead of relying on a single, global attention mechanism, the model employs multiple attention levels. This approach enables the model to adaptively focus on salient image regions, capturing fine-grained spatial dependencies and intricate patterns crucial for accurate recognition. The residual connections help capture and propagate important information through the network. Additionally, the model incorporates depthwise separable convolution, batch normalization, and the Swish activation function. This combination improves computational efficiency and bolsters generalization, enabling the model to adapt effectively to diverse interaction scenarios. The Swish activation enhances non-linearity, and batch normalization aids in stable training, reducing overfitting risks. The proposed model offers a distinct advantage over other existing deep learning models for H2H Interaction recognition from images by incorporating the GELU (Gaussian Error Linear Unit) activation function instead of the traditional ReLU (Rectified Linear Unit) in the fully connected Dense layers. GELU activation, known for its smoothness and non-linearity, provides an essential edge to this model. In contrast to ReLU, which can suffer from vanishing gradients in deeper networks, GELU maintains gradient flow, facilitating the learning process in a deeper architecture.

Combining multi-level self-attention, efficient convolutional operations, and enhanced activations, this model excels in capturing nuanced details and spatial relationships, offering superior generalization for human interaction recognition from images, surpassing existing models in this field.

The proposed model mainly classifies the Human-Human Interaction images into fifteen categories: Celebrating, Dancing, Dining, Handshaking, Hugging, Protesting, Punching, Pointing, Waving, Kicking, Kissing, Highfive, RaisingHands, Talking, Teaching.

The main contributions of this research are: (a) Creation of a novel image dataset for the recognition of Human-Human Interactions (H2HID) with comprehensive data labelling. (b) Recognition of Human-Human Interaction in images is carried out using the proposed AdaptiveDRNet with Multi-level Attention. (c) Introduction of Regularized Categorical Cross-entropy (RCCE) Loss Function. (d) The model proposed in this study is assessed on three related standard benchmark datasets, HII, HIIv2 and Stanford40. (e) Result analysis with various well-established deep learning models based on accuracy and trainable parameters.

The structure of this research paper can be outlined as follows: The comprehensive exploration of related works is discussed in Section II. Section III delves into the intricacies of our proposed method, meticulously detailing our approach, which encompasses data preparation, the network architecture of the proposed model, and details of the loss function utilized. Section IV delves into the experimental results with various standard models on our curated H2HID dataset using various performance metrics and analysis of results with various available related datasets based on accuracy and the number of trainable parameters. The final section summarizes our unique contributions, emphasizing significance and discusses the future scope of this research.

## II. RELATED WORKS

The study of human-human interactions (HHI), human-object interactions (HOI), human-computer [4] interaction (HCI) and human actions has been a prominent research focus [5] in the analysis of video sequences. However, it is noteworthy that there has been a noticeable decrease in the volume of research dedicated to exploring these topics when shifting the focus from video sequences to static still images. Tanisik et al. [6] introduced a range of facial region-based descriptors in their research. Their experiments revealed that while these facial descriptors offer valuable insights, their standalone use yields less effective results. However, when integrated with global scene features, particularly deep features, the proposed facial descriptors exhibited enhanced recognition performance and demonstrated the capability to recognize human interactions in static images. The authors have attained 80.11% accuracy using their collected Human Interaction image dataset. Gong et al. [7] introduced a new image dataset containing four distinct categories of human interactions. Li et al. [8] proposed a new method for transferring knowledge from images to videos, which adapts well to video data with limited training samples. They employ class-specific spatial attention maps within Convolutional Neural Networks (CNNs) to transform video frames into a condensed feature representation. Their ap-

proach incorporates a new Siamese EnergyNet framework, optimizing two loss functions to enhance attention maps aligned with ground truth concepts. They have attained 96.8% accuracy on HII data using the fine-tuned ResNet101 model. In another study, Tanisik et al. [9] delved into the significance of human poses in discerning human interactions within still images. Their novel approach introduces a multi-stream convolutional neural network architecture, harmonizing diverse human pose information to enhance human interaction recognition. Various pose-based representations are scrutinized, and extensive experimentation on an expanded benchmark dataset validates the efficacy of their multi-stream pose CNN in distinguishing a broad spectrum of human interactions and poses. When coupled with contextual information, it serves as a valuable tool for discriminative insights into human-human interactions. They have attained 92.78% accuracy in recognizing human interactions. Verma et al. [10] have employed a feature-based neural network to identify human interactions in images. Tang et al. [11] devised a novel approach to enhance vision-based safety compliance checks by explicitly categorizing worker-tool interactions. Their human-object interaction recognition model, built upon this detector and dataset, also delivered impressive results. On the other hand, Zhou et al. [12] tackled the detection and recognition of Human-object interactions (HOI) in images. They introduced a cascaded parsing net (CP-HOI) that employs a multi-stage, structured approach for HOI understanding. CP-HOI refines HOI proposals through instance detection and structured interaction reasoning (SIR) modules, utilizing a graph parsing neural network (GPNN) to represent HOI structures as interconnected graphs, enhancing contextual information extraction for better interaction comprehension.

On the contrary, there is a substantial body of literature dedicated to the recognition of human interactions in video streams. Numerous references, such as Zhou et al. [13] and Tapaswi et al. [14], have extensively explored this domain by utilizing traditional classification techniques. Nguyen et al. [15] utilize handcrafted features in conjunction with a three-layer convolutional neural network for model training. Yan et al. [16] introduce a CNN-based network to extract features, while Shu et al. introduce Hierarchical Long Short-Term Memory (HLSTM) network [17] to handle temporal information. Alazrai et al. [18] introduced an H2H interaction video dataset having 12 interactions giving more focus on the Pointing, Kicking and Punching interaction. Lee et al. [19] have recognized eight different interactions. Guerdelli et al. [20] provided a comprehensive overview of interpersonal relation recognition datasets and well-established methods, aiding researchers in gaining deeper insights into their characteristics.

Human interaction recognition is a specific area within the broader field of human action recognition. Thus, in addition to our focus on human interaction, we have also listed some notable and relevant existing research and studies in the field of action recognition. Zhang et al. [21] introduced an approach for recognizing actions in static images while minimizing the need for extensive annotations. Luo et al. [22] employed an improved EfficientNet framework to recognize human behaviours. In another study, Yu et al. [23] have proposed a deep ensemble learning model to recognize human actions in still images. In our prior research endeavours focused on Action Recognition, our primary objective was to predict various workout actions from still images [24], subsequently

classifying them into ten distinct workout categories. It's worth highlighting that the proposed WorkoutNet model showcased a remarkable validation accuracy of 92.75% when rigorously assessed on our WAId dataset. Siyal et al. [25] have proposed a Residual CNN model for feature extraction and SVM as a classifier to categorize human actions in still images. Saif et al. [26] have proposed an InceptionResNetV2-based CNN-LSTM model to recognize actions in videos.

Existing standard image datasets HII [27] and HIIv2 [6] have been pivotal in driving progress in the field of human interaction recognition. However, these publicly available datasets often lack specificity in terms of interaction types. The publicly available HII [27] dataset initially focused on four distinct human interaction categories, while the HIIv2 [6] dataset expanded this scope to include ten different human interaction classes. To further enhance the resources available for researchers and practitioners in the field, we have introduced the Human-Human Interactions Image dataset (H2HId), which comprises fifteen diverse types of human interactions. Our primary objective is to furnish the research community and professionals with valuable assets that can be utilized to develop and assess models designed to classify and recognize human interactions depicted in images accurately. This dataset will contribute to enhancing the generalization capabilities and real-world applicability of Human-human interaction recognition models, particularly in the context of interaction recognition.

The proposed AdaptiveDRNet model revolutionizes human interaction recognition from still images with multi-level self-attention, efficient convolution, and GELU activation. It dynamically adapts focus, captures fine details, and maintains gradient flow, outperforming traditional models.

## III. PROPOSED METHOD

The method commenced by gathering human interaction images and standardizing them to a consistent size with augmentation. Subsequently, the curated dataset underwent division into training, validation, and test sets. Data augmentation was employed to enhance the training data. The proposed model, integrated with Callback functions, facilitated model training and extraction of image features. Ultimately, human-human interactions were categorized using the last layer of the proposed model, specifically the Softmax layer. The illustration of the proposed method can be visualized from Fig. 1.
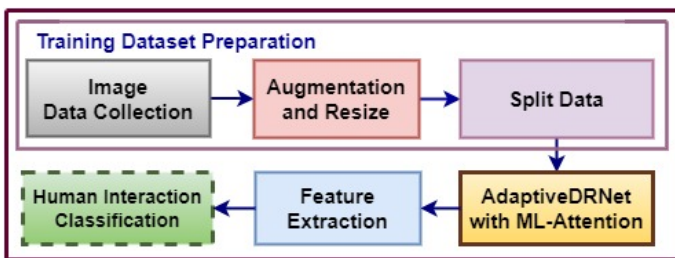


Fig. 1. Illustration of the proposed approach's workflow.

Recognizing the need for research methodologies that can perform efficiently with limited computational resources, this study introduces the AdaptiveDRNet with Multi-level

Attention to recognize various human interactions in still images. The subsequent sections provide detailed insights into the following aspects: a) Training dataset preparation, b) *AdaptiveDRNet with ML-Attention*: Model Architecture, c) Description of the employed loss function, and d) Advantage of AdaptiveDRNet ML-Attention model.

### A. Dataset Preparation

The dataset capturing Human-human interactions (H2HId) has been meticulously curated, enhanced through augmentation techniques, and then resized all images to a uniform resolution of 224 x 224. The collected images are in RGB. There are a total of 15 different human interaction categories. Some sample images of the collected H2HId dataset are highlighted in Fig. 2. The dataset details are given in Section IV(A).



Fig. 2. H2HId data sample.

Recognizing the significant demand for ample training data in deep learning models, we employed the data augmentation technique to bolster the overall performance of the AdaptiveDRNet with ML-Attention model. This approach entailed enlarging the training dataset and mitigating the risk of overfitting. We introduced random transformations, including a zoom range of 0.18, a contrast range of 0.23, rotations ranging from 0 to 25 degrees, and horizontal flips. These random transformations effectively generated additional training data, thereby exposing the training model to a wider array of potential data distribution characteristics. Furthermore, the H2HId dataset has been methodically split into three separate subsets following a precise distribution: 61% of the data is assigned for training, 20% for validation, and 19% for testing. This partitioning strategy adheres to established best practices in deep learning.

### B. AdaptiveDRNet with ML-Attention: Model Architecture

The proposed Adaptive Deep Residual Network (Adaptive-DRNet) with Multi-level Attention model architecture comprises an initial convolutional layer with 32 filters, followed by three sets of residual blocks with attention mechanisms. The model begins with an input layer configured to accept RGB images with dimensions of 224x224 pixels. The initial layer is a 2D convolutional layer with a 3x3 kernel, utilizing 32 filters and applying the GELU activation function, followed

by batch normalization. Subsequently, three residual blocks with Self-Attention mechanisms are employed. Each block encompasses a depthwise convolution layer with a 3x3 kernel and either a stride of 1 (for the first block) or 2 (for subsequent blocks), maintaining spatial dimensions with 'same' padding. Batch normalization and Swish activation functions follow. The block also features a 1x1 convolutional bottleneck with varying filter sizes (64, 128, and 256, respectively, for each block) to capture and transform features. Self-Attention layers are introduced to capture long-range dependencies within the data. The model also comprises a Global Average Pooling (GAP) layer, succeeded by two dense layers consisting of 128 and 256 units, both utilizing GELU activation and dropout with a rate of 0.15 for regularization. Finally, the output layer is a dense layer employing the softmax activation function for classification into 15 human interaction classes. The model has 419,279 trainable parameters. This architecture offers a versatile and customizable framework for image classification tasks, with the flexibility to fine-tune hyperparameters based on specific datasets and requirements. The layered diagram representing the proposed AdaptiveDRNet with ML-Attention model, which is employed to implement the proposed work, is illustrated in Fig. 3.
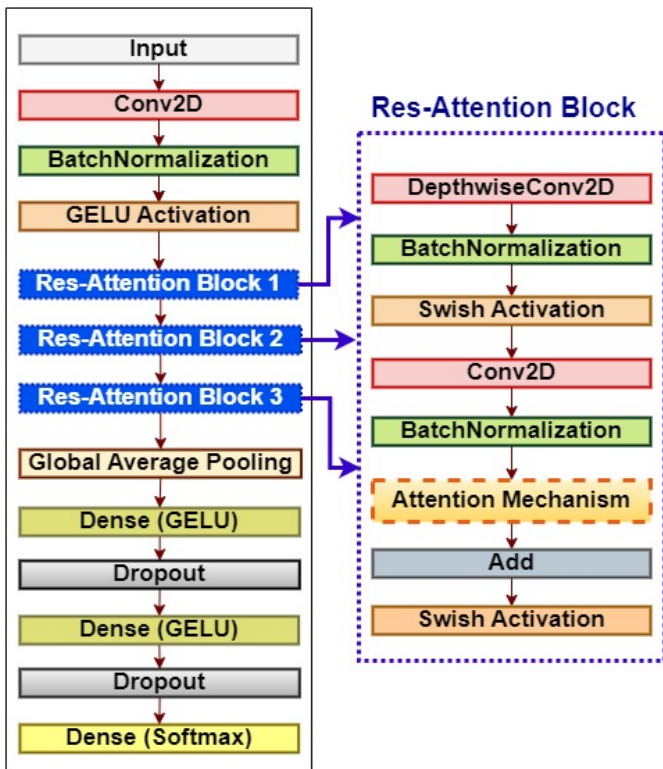


Fig. 3. Proposed adaptiveDRNet ML-attention model.

The proposed AdaptiveDRNet ML-Attention model architecture is outlined as follows:

Input Layer: The model takes input images with a shape of 224x224 pixels and three color channels (RGB).

Initial Convolution Layer: The input images are processed by a convolutional layer with 3x3 kernels having 32 filters, batch normalization (BatchNorm) layer, and a GELU activation function. This layer extracts basic features from the input

images. The choice of a GELU activation function is pivotal, as it captures non-linearities more effectively than traditional activation functions. This layer's primary role is to extract low-level features from input images while maintaining spatial dimensions. Batch normalization aids in faster convergence and mitigating overfitting, ensuring smoother training. The first convolution layer applies a set of filters to the input, followed by batch normalization and a GELU activation function, which introduces non-linearity. The 2D convolution operation is represented as illustrated in Eq. (1). Here, $y(q, r)$ is the output at position $(q, r)$ denotes the feature map, $x(q, r)$ represents the input feature map, $w(l, m)$ are the convolutional filter weights and $b$ denotes the bias term.

$$y(q,r) = \sum_{l=0}^{L-1} \sum_{m=0}^{M-1} x(q+l, r+m) \cdot w(l,m) + b \quad (1)$$

Batch Normalization Layer (BatchNorm): Batch Normalization is a method employed to standardize the output of a layer. This process involves subtracting the mean of the batch and dividing it by the batch standard deviation. This process can be mathematically represented as illustrated in Eq. (2). In this equation, $y_B$ represents the normalized output, $I$ is the input to the BatchNorm layer, $\mu$ denotes the batch mean, $\sigma^2$ stands for the batch variance, $\beta$ denotes the shifting parameter (learnable), $\epsilon$ is a small constant added for numerical stability, $\gamma$ represents scaling parameter (learnable).

$$y_B = \frac{I - \mu}{\sqrt{\sigma^2 + \epsilon}} \cdot \gamma + \beta \quad (2)$$

Res-Attention Block: The proposed model comprises three Residual Attention (Res-Attention) blocks that serve as a powerful feature extraction unit. This block consists of several key layers, starting with a depthwise separable convolutional layer, followed by the BatchNorm layer and the Swish activation. Each block follows a consistent pattern, commencing with depthwise convolution, which performs spatial convolutions independently for each channel, preserving spatial dimensions. This is particularly beneficial for capturing fine-grained details in the image.

The DepthwiseConv2D layer performs a depthwise convolution operation, where each input channel is convolved separately with its own set of learnable filters. The DepthwiseConv2D operation can be represented as illustrated in Eq. (3) The operation is performed independently for each input channel, resulting in an output with the same number of channels as the input. Here, $Y_{i,j,k}$ is the value of the output feature map at position $(i, j)$ and channel $k$, $X_{(i+d-1),(j+e-1),k}$ is the value of the input feature map at position $(i + d - 1, j + e - 1)$ and channel $k$, $K_{d,e,k}$ is the value of the depthwise convolution filter at position $(d, e)$ and channel $k$, $B_k$ is the bias term for channel $k$ and the summation is over the filter size $D$ and both spatial dimensions.

$$Y_{i,j,k} = \sum_{d=1}^{D} \sum_{e=1}^{D} X_{(i+d-1),(j+e-1),k} \cdot K_{d,e,k} + B_k \quad (3)$$

The proposed model incorporates Swish activation functions [28], a choice made due to their well-known smoothness

characteristics and effectiveness in enhancing overall model performance. Subsequently, a 1x1 convolutional bottleneck further processes the features. The distinctive feature is the Self-Attention Layer, which calculates attention scores between spatial locations, allowing the block to weigh the significance of different regions and capture global dependencies. Like the residual blocks, the Attention Block includes a residual connection that adds the Self-Attention output to the original input feature map. This combination of residual connections and Self-Attention enables the block to effectively capture both local and long-range contextual information, making it a valuable building block for image recognition tasks where understanding spatial relationships and context is crucial for accurate classification.

Attention Mechanism: The role of the attention mechanism is pivotal in augmenting the performance of the proposed AdaptiveDRNet model. The attention mechanism, based on the scaled dot-product attention mechanism, is employed to selectively emphasize and de-emphasize features within the intermediate representations of the network. Its importance lies in its ability to capture and focus on crucial information while discarding less relevant details. The attention mechanism is represented using mathematical equations illustrated in Eq. (4), Eq. (5) and Eq. (6).

At first, the Query (Q), Key (K), and Value (V) are obtained by projecting the input (X) using learnable weight matrices $W_q$, $W_k$, and $W_v$, respectively.

$$Q = X \cdot W_q \quad K = X \cdot W_k \quad V = X \cdot W_v \qquad (4)$$

The attention logits are calculated as the dot product of Q and K, scaled by the square root of the dimension of K. Here, $d_k$ denotes the dimension of the key vectors.

$$Att_{Logits} = \frac{Q \cdot K^T}{\sqrt{d_k}} \qquad (5)$$

The attention weights are computed by applying the softmax function to the attention logits ($Att_{Logits}$) as illustrated in Eq. (6).

$$Att_{Weights} = \text{softmax}(Att_{Logits}) \qquad (6)$$

Finally, the attention output is obtained by taking the weighted summation of the values (V) utilizing the attention weights ($Att_{Weights}$) as illustrated in Eq. (7).

$$Att_{Output} = \text{Att Weights} \cdot V \qquad (7)$$

Here, the "Multi-level Attention" aptly characterizes the attention mechanism within our proposed model due to its ability to operate on multiple levels or scales of information. This means that it can simultaneously focus on fine-grained details and broader context within the input data. It's not limited to a single level of attention but rather incorporates various levels, making it a versatile tool for capturing nuanced relationships and patterns in the data. The attention mechanism's significance in the proposed model is multifaceted.

Firstly, it aids in the model's ability to focus on relevant regions of the input, thereby improving feature selection. Secondly, it enhances feature refinement by amplifying important information. Lastly, it facilitates gradient flow during training, as it provides a clear path for gradients to propagate through the network.

Global Average Pooling (GAP) Layer: After the residual attention blocks, GAP is performed, which reduces the spatial dimensions to a single vector for each feature map while retaining essential information. This operation helps in creating a fixed-size representation of the features extracted by the previous layers. GAP calculates the average value of each feature map, effectively summarizing the presence of specific features across the entire image. This is essential for making the model translation-invariant, allowing it to recognize objects regardless of their position in the image. GAP contributes to reducing the model's computational complexity and parameters, making it more efficient. The GAP operation is represented using Eq. (8). Here, $GAP(Y_3)[c]$ represents the spatial average value of channel $c$ in the feature map $Y_3$, which is the output of Res-Attention Block 3 in the model. $K$ and $L$ are the spatial dimensions of the feature map, and $C$ is the number of channels. The GAP operation is applied independently to each channel, calculating the spatial average of values across the entire spatial region of $Y_3$.

$$GAP(Y_3)[c] = \frac{1}{K \cdot L} \sum_{i=1}^{K} \sum_{j=1}^{L} Y_3[i,j,c] \qquad (8)$$

Fully Connected Layers: The proposed model comprises two dense layers (fully connected) with GELU activation. The initial dense layer comprises 128 units, succeeded by a dropout layer configured having a 0.15 dropout rate, strategically employed to mitigate overfitting. The subsequent dense layer consists of 256 units, accompanied by yet another dropout layer with an identical dropout rate. These layers enable the model to learn complex patterns and relationships in the feature representations produced by the earlier layers. The dropout layers further prevent overfitting by randomly deactivating a fraction of neurons during training.

The GELU activation function applied to the fully connected dense layer is mathematically represented using Eq. (9). This activation function introduces a layer of non-linearity into the network, enabling it to capture intricate relations and patterns within the data. Let's denote the input to the fully connected layer as I, which is a vector of activations from the previous layer. The GELU activation denoted by G(I) is applied element-wise to each element of the input I. In Eq. (9) and Eq. (10), I represents the input to the fully connected layer, $\tanh$ is the hyperbolic tangent function, $\sqrt{\frac{2}{\pi}}$ is a constant and 0.044715 is a constant. GELU helps with the vanishing gradient problem and is utilized in the proposed model for improved performance.

$$G(I) = \frac{1}{2}I\left(1 + \tanh(R1)\right) \qquad (9)$$

$$R1 = \left(\sqrt{\frac{2}{\pi}}\left(I + 0.044715I^3\right)\right) \qquad (10)$$

Output Layer: The ultimate layer of the proposed model consists of a dense layer comprising 15 units, as there are 15 human interaction categories. It employs softmax activation to produce probabilities for each human interaction class, making it suitable for multi-class classification.

The illustration in Fig. 4 emphasizes the filter outputs stemming from an image belonging to the 'Pointing' interaction class. Specifically, it highlights the outputs originating from the 1st DepthwiseConv2D layer (1st Res-Attention block), the 2nd DepthwiseConv2D layer (2nd Res-Attention block), and the 3rd Conv2D layer (2nd Res-Attention block). It's worth noting that the numbering of these layers aligns with the sequence provided in the layered diagram of the model, which is depicted in Fig. 3.
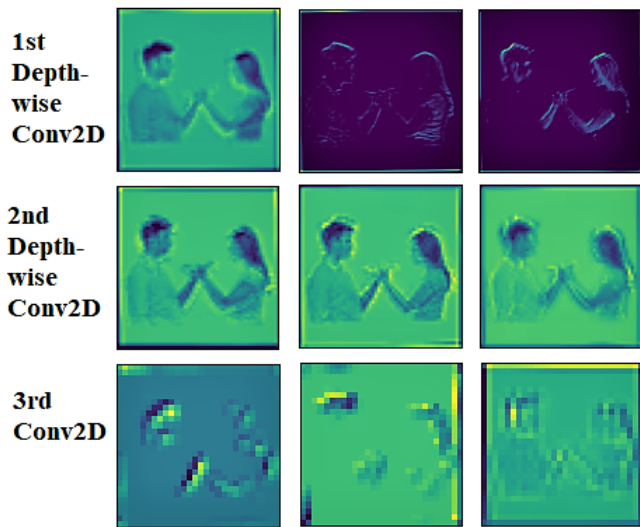


Fig. 4. Feature map visualization of some layers.

Thus, this model architecture incorporates convolutional layers for feature extraction, deep residual blocks with attention mechanisms to capture important features, global average pooling to reduce spatial dimensions, and fully connected layers with dropout enable classification. The attention mechanism between the convolutional layers allows the model to focus on relevant image regions, which can be crucial for tasks with complex visual patterns. The final output layer provides class probabilities for making predictions.

The proposed AdaptiveDRNet model architecture is meticulously designed to capture features at different levels, from low-level details to high-level contextual information with Multi-level Self Attention. The Self-Attention mechanism is a key innovation, enhancing the model's ability to capture spatial relationships, making it well-suited for image classification tasks where context and object dependencies are critical. The Multi-level Attention mechanism enables the model to adaptively focus on important features within the data, enhancing feature selection and representation learning.

### C. Loss Function Details

In addressing the multi-class nature of this study, the Regularized categorical cross-entropy (RCCE) loss function is employed to quantify the error that the model seeks to decrease throughout its training. The Standard categorical cross-entropy loss ($SCCE_{Loss}$) is expressed as illustrated in Eq. (11). Here, $y_{\text{tp}}^{(k)}$ represents actual probability of class $k$ and $y_{\text{pp}}^{(k)}$ represents the anticipated probability of class $k$.

$$SCCE_{Loss} = -\sum_{k=1}^{M=15} y_{\text{tp}}^{(k)} \cdot \log(y_{\text{pp}}^{(k)}) \qquad (11)$$

The $RCCE_{Loss}$ function adds an extra term, which is the L2 regularization [29] term (LT), to the standard loss as mathematically illustrated in Eq. (12).

$$RCCE_{Loss} = SCCE_{Loss} + LT \qquad (12)$$

The L2 regularization term (LT) is mathematically expressed as shown in Eq. (13). Here, $y_{\text{tp}}$ denote the true probability distribution (one-hot encoded labels) of class membership, $y_{\text{p}}$ denote the predicted probability distribution (model's output) of class membership and value of $M$ is 15 which denotes the number of interaction classes in the dataset.

$$LT = \sum_{k=1}^{M=15} (y_{\text{tp}}^{(k)} - y_{\text{pp}}^{(k)})^2 \qquad (13)$$

The Nadam optimizer is then utilized with an initial learning rate set at 0.001 to effectively reduce the error function linked to the proposed model.

### D. Advantage of AdaptiveDRNet ML-Attention Model

In the proposed model, three residual blocks with attention having varying filter sizes (64, 128, 256) help in hierarchical feature extraction. The use of multiple residual blocks with increasing filter sizes allows the model to learn hierarchical features from low-level to high-level representations. Smaller filter sizes (64) in the initial layers help capture fine-grained details and edges, while larger filter sizes (128 and 256) in subsequent layers capture more abstract and complex features. Each residual block typically includes a convolutional layer with a stride greater than 1, which downsamples the spatial dimensions of the feature maps. Starting with a stride of 2 in the first block and possibly increasing it in later blocks helps reduce the spatial resolution of the feature maps. This downsampling reduces computational complexity and increases the receptive field of the network. By using progressively larger filter sizes, the model increases its capacity to learn more complex patterns and features in the data. The skip connections in residual networks enable the reuse of features from prior layers. With multiple blocks, each incorporating its attention mechanism, the model can selectively leverage features from different network stages. This allows the model to focus on fine-grained and high-level features, improving prediction. Therefore, the design choice of three residual blocks with attention and varying filter sizes facilitates efficient feature learning and representation across different scales and complexities.

## IV. EXPERIMENTAL RESULTS

This proposed research is conducted in Google Colab using Python programming, emphasising resource efficiency without utilizing any GPU. It leverages an Intel-Xeon CPU with 2.3GHz clock speed, 13GB of RAM, and approximately 80GB of disk space, diverging from the current practice of relying on GPUs for deep learning tasks. In this section, we have provided the details of our curated H2HId dataset, including available datasets, thorough performance evaluation, and comprehensive analysis of the results.

### A. Dataset Details

Several publicly accessible datasets related to human interactions include HII [27], HIIv2 [6], and Stanford40 [30]. In this work, we have introduced a substantial dataset called the Human-Human Interaction Image dataset (H2HId) [1], a comprehensive collection of images sourced from a variety of online platforms and social media. To ensure effective categorization, images depicting diverse human interaction scenarios were systematically organized into distinct directories. The H2HId dataset is noteworthy for its unbiased representation of human interactions across various individuals and scenarios, aiming for universality without demographic, ethnic, or regional bias. The proposed dataset encompasses a diverse range of human interactions, encompassing 15 distinct categories and containing a total of 4,049 images. The human interaction categories considered are *Celebrating*, *Dancing*, *Dining*, *Handshaking*, *Hugging*, *Protesting*, *Punching*, *Pointing*, *Waving*, *Kicking*, *Kissing*, *Highfive*, *RaisingHands*, *Talking*, *Teaching*.

### B. Performance Evaluation

The effectiveness of the proposed research is assessed through a range of metrics, including measures like training and validation accuracy, F1-score ($F1_s$), AUC-score, classification performance, and the analysis of the confusion matrix.
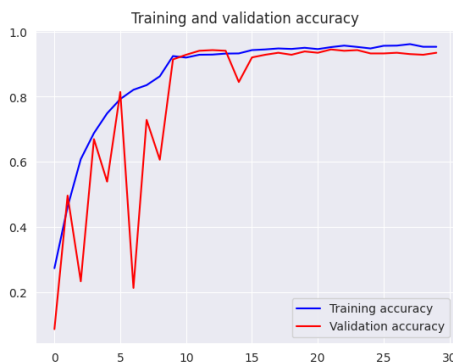


Fig. 5. Accuracy curve of proposed adaptiveDRNet attention model.

Fig. 5 illustrates the proposed model's training and validation accuracy curve. It is seen from the curve that the proposed model shows 99.57% train accuracy and 97.20% validation accuracy. After 28 epochs, the performance of the proposed model did not improve much, so we stopped the

---
[1]H2HId Dataset Link: https://sites.google.com/view/h2hid/home

training process at that point by utilizing the callback functions. The hyperparameters of the proposed AdaptiveDRNet ML-Attention model are highlighted in Table I.

TABLE I. HYPERPARAMETERS OF PROPOSED MODEL

| Parameter(s) | Considered Value |
|---|---|
| Input Shape | 224X224 |
| Batch Size | 5 |
| Epochs | 28 |
| No. of Classes | 15 |
| Kernel | 3X3 |
| Initial Learning Rate | 0.001 |
| Loss Function | Regularized CCE |
| Metrics | Accuracy |
| Optimizer | Nadam |

The proposed work has been evaluated with several benchmark deep learning models, all of which were trained from scratch. Table II presents the training accuracy (Train Acc) and validation accuracy (Val. Acc) and F1-Score ($F1_s$) of VGG-16, ResNet50, InceptionResNetV2, NASNet Mobile, ConvXNet, EfficientNet [22], and our proposed model on the H2HId dataset. The proposed model significantly outperforms the benchmark deep models in terms of accuracy and achieves an impressive 97.20% accuracy on the validation data, surpassing the performance of the EfficientNet [22], NASNet Mobile, ConvXNet, InceptionResNetV2, ResNet50 and VGG-16 model. Additionally, the InceptionResNetV2, NASNet Mobile, ConvXNet and EfficientNet [22] models also exhibited strong performance in classifying the images of the H2HId dataset, achieving validation accuracies (Val. Acc) of 95.30%, 94.76%, 94.60%, and 96.52% respectively.

TABLE II. ASSESSMENT OF DEEP LEARNING MODELS' PERFORMANCE ON H2HID DATASET

| Model | Train Acc | Val. Acc | $F1_s$ | AUC |
|---|---|---|---|---|
| VGG-16 | 96.21% | 94.27% | 0.92 | 0.95 |
| ResNet50 | 97.08% | 94.54% | 0.93 | 0.96 |
| InceptionResNetV2 | 97.61% | 95.30% | 0.95 | 0.98 |
| NASNet Mobile | 97.85% | 94.76% | 0.94 | 0.97 |
| ConvXNet | 98.28% | 94.60% | 0.94 | 0.97 |
| EfficientNet [22] | 98.70% | 96.52% | 0.95 | 0.98 |
| **Proposed Model** | **99.57%** | **97.20%** | **0.96** | **1.0** |

When considering the F1-score ($F1_s$), the Proposed Model performed exceptionally well, achieving the highest $F1_s$ of 0.96, whereas the EfficientNet [22], and InceptionResNetV2 model achieved the second highest $F1_s$ of 0.95 on our H2HId dataset. This indicates that the proposed model exhibits a balanced combination of precision and recall score, making it highly effective in human interaction classification. However, it's worth noting that the proposed model maintains its high $F1_s$ while simultaneously achieving the highest validation accuracy, demonstrating its consistency and robustness in performance. In evaluating deep learning models on the H2HId dataset, their performance was further assessed using Area Under Curve (AUC) scores [31], a crucial metric for measuring their ability to discriminate between positive and negative instances. The results revealed that the Proposed Model stands

out as the top performer with a perfect AUC score 1.0. This achievement showcases its exceptional capability in effectively distinguishing between classes. Following closely, the EfficientNet [22] and InceptionResNetV2 model exhibited strong performance with an AUC score of 0.98. In comparison, the other models, including InceptionResNetV2, NASNet Mobile, ConvXNet, ResNet50, and VGG-16, demonstrated descending levels of AUC scores, with the VGG-16 model having the lowest AUC score at 0.95. These findings emphasize the superiority of the proposed model and EfficientNet [22] in terms of their ability to discriminate between positive and negative instances on the H2HId dataset.

Confusion Matrix: It provides a clear and informative snapshot of a model's predictions aligning with actual ground truth values. In this visualization, the rows represent the true or actual classes, while the columns depict the predicted classes. Each cell in the matrix indicates the number of instances that fall into a particular category. The confusion matrix of the H2HId dataset utilizing the proposed model is depicted in Fig. 6. It serves as a powerful tool for fine-tuning and optimizing classification models.
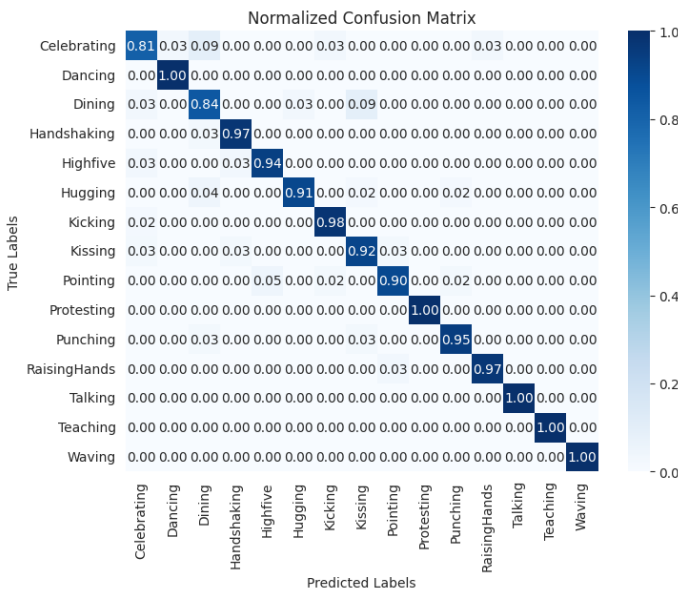


Fig. 6. Confusion matrix of H2HId dataset utilizing proposed model.

Classification Performance: The performance of our Proposed model in classifying human interactions is visually depicted in Fig. 7, showcasing the F1-scores ($F1_s$) for the H2HId dataset.

It is observed that most of the interaction categories in the H2HId dataset exhibit high $F1_s$, exceeding 0.95. However, a few categories, such as "Celebrating" (0.85 $F1_s$), "Dining" (0.90 $F1_s$), "Hugging" (0.93 $F1_s$), and "Pointing" (0.92 $F1_s$), demonstrate slightly lower but still respectable $F1_s$. The proposed AdaptiveDRNet with Multi-level Attention model demonstrates outstanding classification performance on the H2HId dataset. The proposed AdaptiveDRNet model has accurately predicted all the human-human interaction test image samples taken for further evaluation as depicted in Fig. 8.
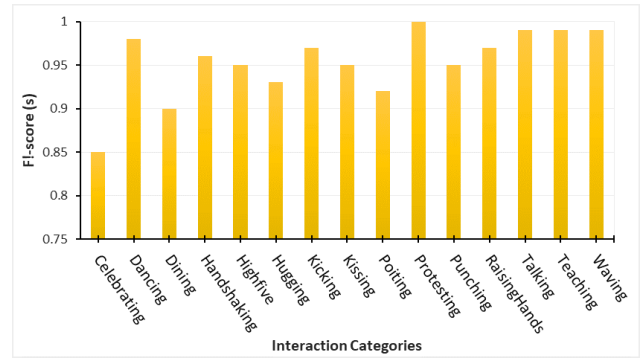


Fig. 7. Classification score of H2HId dataset utilizing proposed model.



Fig. 8. Test result of proposed model.

### C. Result Analysis

The analysis of results with the proposed AdaptiveDRNet with Multi-level Attention model on various Optimizers is depicted in Table III. In this context, the remaining model parameters, including a fixed learning rate (LR) of 0.001, the utilization of the Regularized Cross-entropy loss (RCCE) as the loss function (Loss Func.), a consistent number of training epochs set to 28, and a batch size of 5, were maintained unchanged throughout the optimizer analysis.

TABLE III. ASSESSMENT OF PROPOSED MODEL ON VARIOUS OPTIMIZERS

| Optimizer | Epochs | Loss Fun. | Val. Acc | MCC Val. |
|---|---|---|---|---|
| SGD | 28 | RCCE | 94.20% | 0.9447 |
| RMS | 28 | RCCE | 94.60% | 0.9509 |
| Adagrad | 28 | RCCE | 95.35% | 0.9517 |
| Adam | 28 | RCCE | 96.43% | 0.9640 |
| **Nadam** | **28** | **RCCE** | **97.20%** | **0.9726** |

In the assessment of the proposed model's performance on the H2HId dataset using various optimizers, a nuanced understanding of the optimizer's impact on model accuracy becomes evident. Starting with Stochastic Gradient Descent

(SGD), which achieved a Validation accuracy (Val. Acc) of 94.20%, we observed steady progress with Root Mean Square Propagation (RMS) and Adagrad, reaching Val. accuracies of 94.60% and 95.35%, respectively. However, the Adam optimiser notably improved the model's accuracy, achieving 96.43%. It is observed that the best performance is produced by the use of the Nadam optimizer, which stood out among the optimizers with a remarkable accuracy of 97.20%. These results emphasize the significance of optimizer selection in fine-tuning deep learning models, with Nadam proving to be the most effective choice for maximizing the model's accuracy on the H2HId dataset. Further, the optimizers' performance in the proposed model is evaluated utilizing the Matthews Correlation Coefficient (MCC) values [32] to gauge the quality of multi-class human-human interaction classifications. This metric is crucial in evaluating the model's ability to provide precise predictions while considering both false positives and false negatives. Upon examining the MCC values (MCC Val.) for each optimizer, a clear trend emerged. The Nadam optimizer outshone others, securing the highest 0.9726 MCC value. This achievement signifies a remarkable level of agreement between the model's predictions and the true labels. The Nadam optimizer stands out as the top performer, demonstrating exceptional classification capabilities. This emphasizes the significant influence of optimizer selection on a model's ability to generalize and make accurate predictions.

The proposed technique is compared with various standard CNN models to test the efficacy, as demonstrated in Table IV. It depicts the accuracy results of different deep learning-based models with various benchmark datasets, namely HII [27], HIIv2 [6] and our H2HId dataset. Among all the models considered for evaluation, the proposed model attained the top-most accuracy of 96.38% on the HII dataset, followed by the EfficientNet [22] and EnsembleNet [33] models with 95.83% and 95.37% accuracy, respectively. Our method demonstrated high classification performance on the two benchmark datasets, namely the HII and HIIv2, yielding remarkable accuracies.

TABLE IV. COMPARATIVE EVALUATION OF DEEP LEARNING MODELS IN HUMAN INTERACTION RECOGNITION

| Method(s) | HII | HIIv2 | H2HId | TP (M) |
|---|---|---|---|---|
| VGG-16 | 93.20% | 81.36% | 94.27% | 134.70 |
| ResNet-50 | 93.56% | 81.20% | 94.54% | 25.60 |
| MobileNetv2 | 94.54% | 82.16% | 94.67% | 3.50 |
| DELVS1 [23] | 94.20% | 82.28% | 95.82% | >140 |
| IncepResNetV2 | 95.24% | 82.67% | 95.30% | 55.90 |
| EnsembleNet[33] | 95.37% | 82.40% | 96.21% | – |
| EfficientNet [22] | 95.83% | 83.17% | 96.52% | 1.03 |
| **Proposed Model** | **96.38%** | **83.42%** | **97.20%** | **0.41** |

Notably, the proposed model achieved the highest accuracy across all three datasets, showcasing its exceptional ability to accurately identify human interactions. The proposed model attained 96.38% on HII, 83.42% on HIIv2, and 97.20% on H2HId datasets. On the HIIv2 dataset, EfficientNet [22] and EnsembleNet [33] attain 83.17% and 82.40% accuracy respec-

tively. The InceptionResNetV2 (IncepResNetV2), DELVS1 [23], and EfficientNet [22] model attain 95.30%, 95.82% and 96.52% accuracy, respectively on our H2HId dataset. let's consider the comparison based on the number of trainable parameters (TP). The proposed model features a comparatively streamlined design, comprising merely 0.41 million (M) TP. In contrast, some of the benchmark models have significantly larger numbers of trainable parameters. For instance, VGG-16 and ResNet50 have 134.70 million and 25.60 million TP, respectively. DELVS1 [23] model has $140+$ million TP, IncepResNetV2 has 55.90 M, MobileNetv2 has 3.50 M, and EfficientNet [22] has 1.03 million TP. The proposed model's advantage lies in its ability to achieve superior accuracy while maintaining significantly smaller trainable parameters than these well-established benchmark models. This is particularly important in real-world applications where computational efficiency and memory constraints are critical factors.

The F1-Score ($F1_s$) on both the Stanford40 [30] and the HII [27] datasets demonstrates strong classification performance across multiple established deep learning models, as depicted in Fig. 9. Stanford40 is a still image action dataset with 40 action categories, which is also considered in the analysis.
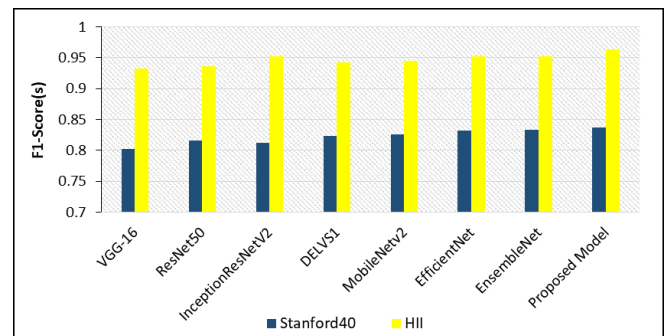


Fig. 9. Performance analysis of various models on stanford40 and HII datasets.

The proposed model emerges as the top performer, showcasing its outstanding classification performance with 0.83 $F1_s$ on the Stanford40 dataset and an impressive 0.96 $F1_s$ on our HII dataset. This model consistently demonstrates superior classification capabilities in recognizing human interactions and actions. Both the EfficientNet [22] and EnsembleNet [33] model attains 0.95 $F1_s$ on HII dataset. The InceptionResNetV2 model achieves 0.81 $F1_s$ on Stanford40, whereas the EnsembleNet [33] model achieves 0.83 $F1_s$ on Stanford40 dataset, and both these model attains $F1_s$ above 0.95 on HII dataset.

## V. CONCLUSION AND FUTURE SCOPE

Human-human interaction recognition from still images using deep learning is a rapidly evolving field with vast implications across various domains. Recognizing complex human interactions from static visual cues using the proposed model finds applications in social behavior analysis, surveillance, market research, education, content tagging, and human-robot interactions. The proposed network in this research combines multi-level attention mechanisms and residual networks to

enhance its ability to recognize human interactions, allowing it to focus on relevant features within images automatically. This approach aims to improve accuracy and effectiveness in recognizing intricate human-human interactions, making it valuable in computer vision and video analysis. The study's main contributions include the development of a new dataset for Human-Human Interaction Recognition (H2HID) with comprehensive labelling, the introduction of a novel AdaptiveDRNet Multi-level Attention Network for recognizing human interactions in images, and an extensive result analysis involving various well-established deep learning models based on accuracy and the number of trainable parameters, utilizing established related benchmark datasets for a comprehensive evaluation. The Multi-level Attention in our model excels by operating on multiple information scales, enabling simultaneous focus on fine-grained details and broader context. Its versatility lies in its ability to encompass attention at various levels, capturing nuanced relationships and data patterns. The suggested model is suitable for operation on devices with limited resources since it employs minimal trainable parameters. This research underscores the potential of deep learning in advancing our understanding of human interactions from visual data and its wide-ranging applications in diverse fields.

The future scope of this research encompasses several promising avenues for further exploration and enhancement. Firstly, there is a significant potential for expanding the dataset size used in this study. A larger dataset would not only increase the diversity and representativeness of human interactions but also enable the model to generalize better across various scenarios. Furthermore, the inclusion of additional and more diverse human interaction categories within the dataset would enhance the model's capability to recognize a broader spectrum of interactions. Another important direction for future research involves the creation of improved classifiers that prioritize energy efficiency to ensure the feasibility and scalability of the proposed work in real-world settings.

## REFERENCES

[1] T. M. Newcomb, R. H. Turner, and P. E. Converse, *Social psychology: The study of human interaction.* Psychology Press, 2015.

[2] A. Stergiou and R. Poppe, "Analyzing human–human interactions: A survey," *Computer Vision and Image Understanding*, vol. 188, p. 102799, 2019.

[3] P. Khaire and P. Kumar, "Deep learning and rgb-d based human action, human–human and human–object interaction recognition: A survey," *Journal of Visual Communication and Image Representation*, vol. 86, p. 103531, 2022.

[4] N. A. Mashudi, M. A. M. Izhar, and S. A. M. Aris, "Human-computer interaction in mobile learning: A review," *International Journal of Advanced Computer Science and Applications*, vol. 13, no. 3, 2022.

[5] W. Xu, M. J. Dainoff, L. Ge, and Z. Gao, "Transitioning to human interaction with ai systems: New challenges and opportunities for hci professionals to enable human-centered ai," *International Journal of Human–Computer Interaction*, vol. 39, no. 3, pp. 494–518, 2023.

[6] G. Tanisik, C. Zalluhoglu, and N. Ikizler-Cinbis, "Facial descriptors for human interaction recognition in still images," *Pattern Recognition Letters*, vol. 73, pp. 44–51, 2016.

[7] W. Gong, J. Gonzàlez, J. M. R. S. Tavares, and F. X. Roca, "A new image dataset on human interactions," in *Articulated Motion and Deformable Objects.* Springer, 2012, pp. 204–209.

[8] J. Li, Y. Wong, Q. Zhao, and M. S. Kankanhalli, "Attention transfer from web images for video recognition," in *Proceedings of the 25th ACM international conference on multimedia*, 2017, pp. 1–9.

[9] G. Tanisik, C. Zalluhoglu, and N. Ikizler-Cinbis, "Multi-stream pose convolutional neural networks for human interaction recognition in images," *Signal Processing: Image Communication*, vol. 95, p. 116265, 2021.

[10] A. Verma, T. Meenpal, and B. Acharya, "Multiperson interaction recognition in images: A body keypoint based feature image analysis," *Computational Intelligence*, vol. 37, no. 1, pp. 461–483, 2021.

[11] S. Tang, D. Roberts, and M. Golparvar-Fard, "Human-object interaction recognition for automatic construction site safety inspection," *Automation in Construction*, vol. 120, p. 103356, 2020.

[12] T. Zhou, S. Qi, W. Wang, J. Shen, and S.-C. Zhu, "Cascaded parsing of human-object interaction recognition," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 44, no. 6, pp. 2827–2840, 2021.

[13] Y. Zhou, B. Ni, R. Hong, M. Wang, and Q. Tian, "Interaction part mining: A mid-level approach for fine-grained action recognition," in *IEEE Conference on Computer Vision and Pattern Recognition (CVPR)*, 2015, pp. 3323–3331.

[14] M. Tapaswi, M. Bäuml, and R. Stiefelhagen, "Storygraphs: Visualizing character interactions as a timeline," in *IEEE Conference on Computer Vision and Pattern Recognition*, 2014, pp. 827–834.

[15] N. Nguyen and A. Yoshitaka, "Human interaction recognition using independent subspace analysis algorithm," in *IEEE International Symposium on Multimedia*, 2014, pp. 40–46.

[16] Y. Yan, B. Ni, and X. Yang, "Predicting human interaction via relative attention model," in *International Joint Conference on Artificial Intelligence (IJCAI-17)*, 2017, pp. 3245–3251.

[17] X. Shu, J. Tang, G.-J. Qi, W. Liu, and J. Yang, "Hierarchical long short-term concurrent memory for human interaction recognition," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 43, no. 3, pp. 1110–1118, 2021.

[18] R. Alazrai, A. Awad, A. Baha'A, M. Hababeh, and M. I. Daoud, "A dataset for wi-fi-based human-to-human interaction recognition," *Data in brief*, vol. 31, p. 105668, 2020.

[19] N.-G. Cho, S.-H. Park, J.-S. Park, U. Park, and S.-W. Lee, "Compositional interaction descriptor for human interaction recognition," *Neurocomputing*, vol. 267, pp. 169–181, 2017.

[20] H. Guerdelli, C. Ferrari, and S. Berretti, "Interpersonal relation recognition: a survey," *Multimedia Tools and Applications*, vol. 82, no. 8, pp. 11 417–11 439, 2023.

[21] Y. Zhang, L. Cheng, J. Wu, J. Cai, M. N. Do, and J. Lu, "Action recognition in still images with minimum annotation efforts," *IEEE Transactions on Image Processing*, vol. 25, no. 11, pp. 5479–5490, 2016.

[22] C.-Y. Luo, S.-Y. Cheng, H. Xu, and P. Li, "Human behavior recognition model based on improved efficientnet," *Procedia computer science*, vol. 199, pp. 369–376, 2022.

[23] X. Yu, Z. Zhang, L. Wu, W. Pang, H. Chen, Z. Yu, and B. Li, "Deep ensemble learning for human action recognition in still images," *Complexity*, vol. 2020, 2020.

[24] A. Dey, A. Dutta, and S. Biswas, "Workoutnet: A deep learning model for the recognition of workout actions from still images," in *2023 3rd International Conference on Intelligent Technologies (CONIT).* IEEE, 2023, pp. 1–8.

[25] A. R. Siyal, Z. Bhutto, S. M. S. Shah, A. Iqbal, F. Mehmood, A. Hussain, and A. Saleem, "Still image-based human activity recognition with deep representations and residual learning," *International Journal of Advanced Computer Science and Applications*, vol. 11, no. 5, 2020.

[26] A. S. Saif, E. D. Wollega, and S. A. Kalevela, "Spatio-temporal features based human action recognition using convolutional long short-term deep neural network," *International Journal of Advanced Computer Science and Applications*, vol. 14, no. 5, 2023.

[27] "Hii dataset [online]," https://zenodo.org/record/831923, Accessed August 19, 2023.

[28] A. Nader and D. Azar, "Evolution of activation functions: An empirical investigation," *ACM Trans. Evol. Learn. Optim.*, vol. 1, no. 2, jul 2021.

[29] X. Li, D. Chang, T. Tian, and J. Cao, "Large-margin regularized softmax cross-entropy loss," *IEEE Access*, vol. 7, pp. 19 572–19 578, 2019.

[30] "Stanford40 [online]," http://vision.stanford.edu/Datasets/40actions.html, Accessed August 19, 2023.

[31] T. Yang and Y. Ying, "Auc maximization in the era of big data and ai: A survey," *ACM Computing Surveys*, vol. 55, no. 8, pp. 1–37, 2022.

[32] G. Jurman, S. Riccadonna, and C. Furlanello, "A comparison of mcc and cen error measures in multi-class prediction," *PLOS ONE*, vol. 7, no. 8, pp. 1–8, 08 2012.

[33] K. Hirooka, M. A. M. Hasan, J. Shin, and A. Y. Srizon, "Ensembled transfer learning based multichannel attention networks for human activity recognition in still images," *IEEE Access*, vol. 10, pp. 47 051–47 062, 2022.

# Keyphrase Distance Analysis Technique from News Articles as a Feature for Keyphrase Extraction: An Unsupervised Approach

Mohammad Badrul Alam Miah[1], Suryanti Awang[2]*, Md Mustafizur Rahman[3], A. S. M. Sanwar Hosen[4]*

Faculty of Computing, Universiti Malaysia Pahang Al-Sultan Abdullah,
26600, Pekan, Pahang, Malaysia[1,2]
Information and Communication Technology,
Mawlana Bhashani Science and Technology University, Tangail-1902, Bangladesh[1]
Center of Excellence for Artificial Intelligence & Data Science,
Universiti Malaysia Pahang Al-Sultan Abdullah, 26300, Gambang, Pahang, Malaysia[2]
Faculty of Mechanical and Automotive Engineering Technology,
Universiti Malaysia Pahang Al-Sultan Abdullah, 26600, Pekan, Pahang, Malaysia[3]
Department of Artificial Intelligence and Big Data, Woosong University, Daejeon 34606, South Korea[4]

*Abstract*—Due to the rapid expansion of information and online sources, automatic keyphrase extraction remains an important and challenging problem in the field of current study. The use of keyphrases is extremely beneficial for many tasks, including information retrieval (IR) systems and natural language processing (NLP). It is essential to extract the features of those keyphrases for extracting the most significant keyphrases as well as summarizing the texts to the highest standard. In order to analyze the distance between keyphrases in news articles as a feature of keyphrases, this research proposed a region-based unsupervised keyphrase distance analysis (KDA) technique. The proposed method is broken down into eight steps: gathering data, data preprocessing, data processing, searching keyphrases, distance calculation, averaging distance, curve plotting, and lastly, the curve fitting technique. The proposed approach begins by gathering two distinct datasets containing the news items, which are then used in the data preprocessing step, which makes use of a few preprocessing techniques. This preprocessed data is then employed in the data processing phase, where it is routed to the keyphrase searching, distance computation, and distance averaging phases. Finally, the curve fitting method is used after applying a curve plotting analysis. These two benchmark datasets are then used to evaluate and test the performance of the proposed approach. The proposed approach is then contrasted with different approaches to show how effective, advantageous, and significant it is. The results of the evaluation also proved that the proposed technique considerably improved the efficiency of keyphrase extraction techniques. It produces an F1-score value of 96.91% whereas its present keyphrases are 94.55%.

*Keywords*—*Curve fitting technique; data pre-processing; data processing; feature extraction; KDA technique; keyphrase extraction*

## I. INTRODUCTION

In the past fifteen years, the paradigm for consuming news has changed from traditional print newspapers to individualized online news aggregation platforms like Google News, News360, and Yahoo! News. These systems gather a lot of news from many sources, aggregating it and presenting it on their respective mobile apps and websites [1], [2]. But now, the dramatic increase in textual news and the continual development of technology make it far more difficult to manage such a vast volume of news. People could just handle this enormous amount of news manually, which took a lot of time before technology was developed [3]. Developing automated keyword extraction techniques that replace manual tasks by utilizing the extraordinary computing power of computers is due to the difficulty of handling this huge amount of news [4], [5]. High-level keyphrases are extracted from news articles using automatic keyphrase extraction techniques. The keyphrase often offers a high level of document characterization, summarization, and description, which is important for numerous NLP features like content categorization, clustering, and segmentation [3]. However, they are utilized in a variety of online information processing applications, including contextual advertising, recommended systems, digital content management, and information retrieval. It is suitable for use in media searches, legal information retrieval, geographic information retrieval, search engines, and digital libraries [5].

To meet the aforementioned applications, a wide range of keyphrase extraction techniques have already been created, including [6], [7], [8], [9], [10]. Some of them, like domain-specific strategies [6], call for application domain knowledge; others, like linguistic techniques [9], [10], demand language competence. As a result, they are unable to solve issues in different fields, languages, or disciplines. According to [11], supervised machine learning algorithms need a large portion of datasets for training to extract high-quality keyphrases, and they generalize ineffectively beyond the range of trained data. Additionally, it made the system less understandable, required more storage and calculation, and was computationally expensive [12], [4], [13]. Due to the enormous number of complex processes, statistical unsupervised methods like [14], [15], [16] seem to be computationally very expensive. The graph-based unsupervised techniques underperform due to their inability to identify coherence between the many words that make up a keyword [17], [18], [19], [20], [21]. Last but not least,

---

*Corresponding authors. Email: suryanti@ump.edu.my, sanwar@wsu.ac.kr

www.ijacsa.thesai.org

995 | Page

TeKET [22] is incredibly flexible and behaves similarly to the TF-IDF if the data length is short.

Feature extraction is an essential technique in keyphrase extraction for those who want high-quality keyphrases. It is the process of acquiring characteristics (also referred to as features) that distinguish keyphrases or keywords from other terms [23]. These features also affect the effectiveness of various supervised and unsupervised keyphrase extraction methods. Keyphrase distance analysis (KDA) is important for all of those keyphrase extraction methods as a feature that helps to take top-level keyphrases from any article. The KDA technique is used as a feature of such keyphrase extraction techniques to extract keyphrases. Without applying high-quality features, the keyphrase extraction method cannot extract high-quality keyphrases [5]. As an outcome of the previous discussion, it has been determined that keyphrase feature extraction continues to be a crucial research field for the study. So, a region-based unsupervised KDA technique is proposed in this paper for news articles, which led to the following important achievements:

- The proposed technique called keyphrase distance analysis (KDA) introduced new features of keyphrases to calculate the distance of keyphrases from the center point of the news article.

- The proposed technique is corpus-independent, domain-independent, and language-independent.

- The proposed technique can be used by both unsupervised and supervised techniques.

- The proposed technique doesn't depend on document length means that it is a length-free technique.

- Two (2) standard news datasets are utilized to test as well as evaluate the performance of our proposed technique.

The remainder of this article is organized as follows: The various strategies are discussed in Section II along with their advantages and disadvantages, highlighting the demand for a fresh approach. Following that, a region-based unsupervised KDA technique is provided in Section III for figuring out the distance of keyphrases in each region of a news article. The phase of experiments is then thoroughly discussed in Section IV, including information about the datasets, evaluation metrics, and implementation details. The efficiency of the system was then assessed on two (2) standard datasets, and the suggested strategy was compared to existing methods to ascertain its advantages and disadvantages, which are discussed briefly in Section V. Lastly, in Section VI, the research's contributions, follow-up research, as well as flaws, were noted.

## II. RELATED WORKS

The proposed keyphrase distance analysis (KDA) method from news articles can be used as an attribute or characteristic for keyphrase extraction methods [24], [25]. Therefore, similar strategies are covered in this section. There are two common types of keyphrase extraction techniques, depending on the training dataset. One is unsupervised, and the other is supervised. Both techniques can make use of feature extraction methods [3]. The essential components of both techniques will be covered in the following subsections:

### A. Unsupervised Techniques

These techniques, which are categorized as statistical or graph-based techniques, are used to extract keyphrases from documents without any prior knowledge. They are thought to be a ranking issue [26]. PositionRank is a PageRank enhancement that enhances performance by combining word locations and frequency. However, it performs quite poorly, as evidenced by [20]. Another keyphrase extraction method that outperforms TextRank's constraints is TopicRank. Additionally, it has an issue of error propagation, according to [18]. TextRank's extension is SingleRank. Only noun phrases can be correctly extracted from a document. However, it is unable to accurately extract the keywords from the compiled ranked phrases [17]. A method called MultipartiteRank addresses the issue of topic rank, such as error propagation. There is an error in clustering [21]. TeKET is a more famous key extraction method that does not depend on a language or a domain. It requires only basic statistical knowledge. It offers a great deal of versatility, even though it performs better than others [22]. The KP-Miner is used to overcome the problem of preferring single phrases. Despite outperforming TF-IDF, it suffers a decline in performance on a worldwide scale. It is also expensive computationally [14], [27]. Another better technology that can solve the IDF issue is YAKE. For N-grams, however, the computing complexity rises linearly [16].

### B. Supervised Techniques

The extracted keyphrases from any articles using supervised techniques are categorized in a binary fashion, with some candidate keyphrases being labeled as keyphrases and others as non-keyphrases [26]. The classification problem can be solved using a number of well-known methods, including support vector machines (SVM) [28], decision trees (DT), naive bayes [29], neural networks (NN) [23], [30], and so forth. The KEA utilizes the Naive Bayes technique, which uses TFxIDF with the first occurrence location as a feature. However, it may yield subpar results and rely on the training dataset [31]. First appearance position, length of keyphrase, and term frequency (TF) are all automatically taken into account by the Genitor Extractor (GenEx) as features. This system does not make use of the TFxIDF method [26]. The Maui algorithm extended the KEA technique to combine data from Wikipedia. Its primary flaw is a lack of assessment abilities [32]. Informingness, keyphraseness, length of candidate terms, beginning occurrence position, and term position are among the characteristics used by HUMB. Even though it has only used academic papers, it has had positive results across a variety of data sets [33], [25]. The first position of words, relative Pos, POS, keyphraseness, and TFxIDF are all features used by CeKE. It could make keyphrase extraction better [34]. The KeyEx Method significantly improves the quality of the retrieved key. Additionally, this method works better than other consecutive pattern mining methods [35].

The aforementioned discussions demonstrate that supervised and unsupervised keyphrase extraction approaches have a number of distinct disadvantages that prevent them from performing as well as they could. As a result, the proposed KDA technique will assist in minimizing the observed shortcomings and extracting high-quality keyphrases from news articles.
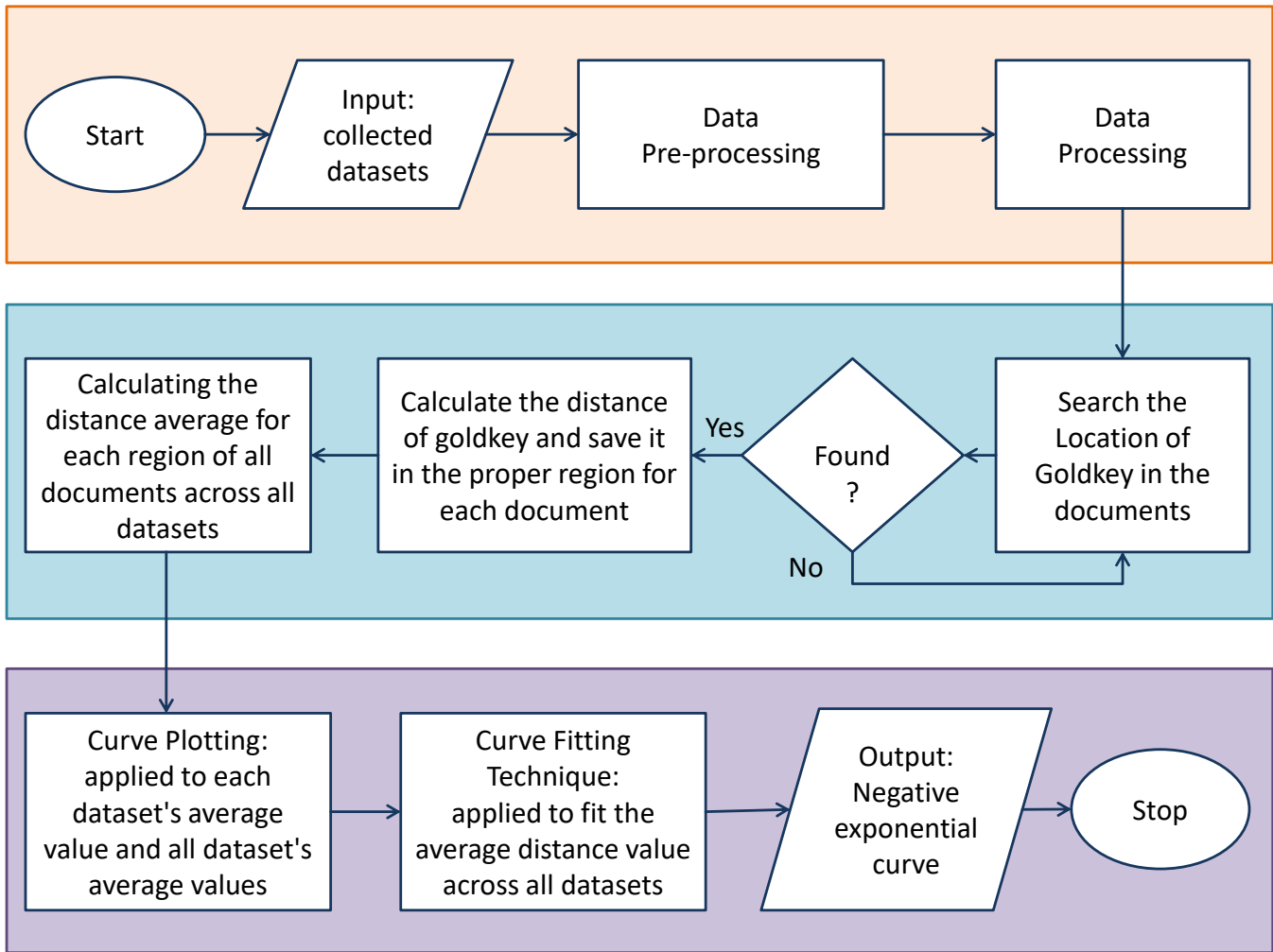
Fig. 1. The architectural flow diagram of proposed KDA technique.

## III. MATERIAL AND METHODS

The eight steps of the proposed KDA technique are depicted in Fig. 1: data collection, data preprocessing, data processing, searching keyphrases or goldkeys, distance computation, averaging distance, curve plotting, and the last, the curve fitting technique. The next subsections explore the proposed approach in more detail.

### A. Data Collection

The suggested technique gathered a total of two datasets that contained news in this phase. The two datasets are 110-PT-BN-KP and 500N-KPCrowd, which contain 610 news articles that cover the languages (English and Portuguese) [36]. Every dataset consists of two different types of files: the "keys file" (which contains keyphrases with the name "goldkeys") and the "documents file" (which has the name "docsutf8" and contains the articles/papers). In Section IV-A, the dataset is described in depth.

### B. Data Pre-processing

After that, the data pre-processing phase receives the collected datasets. The suggested system then separates the

key files and the docsutf8 files. The key files contain several critical keys, and the docsutf8 files contain numerous crucial documents or articles. The docsutf8 files and key files are then read, and they are saved as text files (named text and key, respectively). Afterward, normalization is required to apply to these files, which entails four procedures, such as text conversion to lowercase, removing all the punctuation marks from the text, eliminating empty or white spaces by using the strip() function (delaying all the leading and ending spaces), and removing digits (using regular expressions, non-relevant numbers are removed).

### C. Data Processing

After the data pre-processing phase, the proposed technique tries to determine the total goldkeys depending on the Newline (\n) method from the key files. After that, the proposed approach uses the first appearance keyphrase, assumes the length of the document has eight regions, and then determines the midpoint of each document to calculate the distance of keyphrases from the midpoint.

### D. Goldkey Searching

The proposed method then attempts to determine each goldkeys location *(Loc)* inside the document by taking into account their first occurrence. If the document has the location of Goldkey, it advances to the next phase. If the location of the goldkey cannot be found, try looking for the next goldkey in the document's key file. This procedure will continue until the key file (goldkeys) has been finished for a single document as well as for a single dataset. The exact same process will go on for all datasets.

### E. Distance Calculation

In this phase, the proposed technique must compute the distance *(Dist)* between the document's midpoint and the goldkey location after the data searching step and preserve this *Dist* value in the relevant region of the document. Be aware that this value is preserved in a two-dimensional *(2-D)* array, where each column shows the number of document regions and each row shows the number of goldkeys [25].

### F. Distance Averaging

After distance calculation, it is an important stage. This step involves calculating the distance average *(AVG)* between every region for a document and storing the results in a new *(2-D)* array with the same columns for article regions and rows for the total number of papers in the dataset. Then, until all documents for a particular dataset are finished, this procedure will continue. Similarly, for all documents in a dataset, calculate the distance average for every region in a manner similar to that described before, and then store the result in another *2-D* array, where the column represents the document region's number and the row indicates the total number of datasets. "Then, until all datasets have been completed, this AVG distance-calculating process will continue. Lastly, determine the AVG distance for each region across all datasets" [25].

### G. Curve Plotting (CP)

The CP is a graphical method for representing the collected data. It effectively enables the creation of thoughts that do not emerge from a list of values and visually depicts the link between variables. In data statistics and analysis, CP is crucial. This technique is used to get the idea that keyphrase distance from the document's center depends on the article region in our proposed method. This is the justification for plotting the average or mean distance value of every dataset and the mean distance value for all datasets [25].

### H. Curve Fitting Technique (CFT)

One of the most effective and often used analysis tools is curve fitting, which may be applied to linear, polygonal, and nonlinear curves. Most frequently, it involves creating a mathematical equation or curve that best fits a set of data points that are oriented toward limitations. The suggested approach uses CFT to generate a mathematical equation as well as a curve to determine the distance of keyphrases from the documents' centers and their density in each area. The CFT is then applied to the entire dataset's average value, and the suggested system gets a negative exponential curve as a result.

## IV. Experimental Setup

In this section, the proposed technique explains the experimental setting, the details of the corpus, the evaluation metrics, and the details of how it will be used. The details of how it will be used are explained in more depth in the next subsection. This then anticipates the discussion of the findings in Section V.

### A. Corpus Details

The performance of the suggested technique has been tested on two (2) different datasets. In this proposed system, typical collections like 500N-KPCrowd and 110-PT-BN-KP are used [36]. The datasets have been briefly described in the earlier Section III-A. A table that is shown in Table I explains the number of languages, categories of documents, document's number, goldkey's number, present goldkey's number, the number of present-and-absent goldkeys per document (%), and execution/processing time for each datasets [5], [2].

The dataset named *110-PT-BN-KP*, is a television (TV) broadcast news (BN) related dataset. The European Portuguese ALERT BN corpus contains 110 scripts from eight TV broadcast news programs. These programs cover a wide range of topics, such as banking, sports, and politics" [3]. All terms that made up text content summaries were removed using a tagger, yielding 24.44 goldkeys per document. There are 72 keyphrases that are missing and 2616 keyphrases that are present; processing took 0.047 seconds.

A dataset of broadcast news transcriptions is called the *500N-KPCrowd*. This dataset consists of 500 English-language broadcast news articles from ten different categories, each of which has 50 articles (art and culture, crime, fashion, business, health, world politics, politics, sports, science, and technology) [36]. Along with the processing time of 0.203 sec, it also includes the keyphrases 2265, which is absent, and 22345, which is the keyphrase that is present.

### B. Evaluation Metrics

In our proposed method, the three most significant and relevant measures are used to contrast performance with alternative methods: *Precision, recall, and F1-score*. Here, *Precision* refers to the proportion of correctly predicted values to all positively predicted values. In other words, it is used to determine the positive patterns in a positive class that are successfully anticipated out of the overall projected patterns [5], [2]. The following equation (1) can be used to calculate it:

$$Precision = \frac{Key_{corrected}}{Key_{predicted}} \qquad (1)$$

Where $Key_{corrected}$ is the total correctly predicted keyphrases that are matched with standard keyphrases and $Key_{predicted}$ is the total predicted keyphrases. Similarly, the ratio of precisely expected positive values to actual positive values is known as *Recall*, and it may be calculated using the equation (2):

$$Recall = \frac{Key_{corrected}}{Key_{standard}} \qquad (2)$$

TABLE I. AN OVERVIEW OF THE NEWS DATASET USED TO ANALYZE THE PRESENT AND ABSENT KEYPHRASE / GOLDKEY WITH EXECUTION / PROCESSING TIME

| News Dataset | Language Types | Total Docs | Total Gold-Keys | Total Present Goldkey | Present Goldkey per doc (%) | Absent Goldkey per doc (%) | Processing Time (sec) |
|---|---|---|---|---|---|---|---|
| 110-PT-BN-KP | PT | 110 | 2688 | 2616 | 98.66% | 1.34% | 0.047 |
| 500N-KPCrowd | EN | 500 | 24610 | 22345 | 90.45% | 9.55% | 0.203 |

Where $Key_{standard}$ is the total keyphrases in the standard keyphrase list. Lastly, the weighted average of Precision and Recall is known as *F1-score*. The *F1-score* is calculated by utilizing the below equation (3).

$$F1 - score = \frac{2 \times Precision \times Recall}{Precision + Recall} \qquad (3)$$

### C. Implementation Details

The suggested approach is put into practice using Python 3.6 and the Spyder IDE. Python is very simple and easy to use as well as learn. It's an object-oriented and high-level programming language. It offers a flexible data format that is user-friendly and backed by a number of libraries. It boosts productivity, is interpretive and dynamically typed, and is open-source and free. Python is used in many different fields, such as machine learning, big data, and cloud computing. The computer is outfitted with a 256GB SSD drive, 12GB of RAM, an Intel Core i7 processor, and Win-10 OS [2].

## V. RESULTS AND DISCUSSION

This section discusses the in-depth study of the outcomes of the experiments. If the region's number is raised to more than eight in our proposed technique, the first region is found to have a relatively shorter AVG distance and fewer goldkeys. Likewise, if the region's number is decreased to less than eight, the first region has a bigger AVG distance and more goldkeys. The proposed technique therefore considers the text length to be eight regions rather than varying the number of regions because its goal is to analyze the keyphrase distance from news articles. In this section, the performance of the suggested method is examined under various headings (such as the Results of Dataset Analysis, the Results of Curve Plotting (CP) Analysis, the Results of Curve Fitting Technique, and finally Comparisons of the Suggested Method) that are described in the following subsections.

### A. Result of Dataset Analysis

Two independent datasets (described in IV-A) were used to examine and assess the performance of the proposed approach. The proposed technique attempts to determine the processing time for each dataset from the dataset analysis. It also determines the total of documents, the total of goldkeys, the number of present-absent goldkeys, and the total present-absent keyphrases or goldkeys per document in percentage that are existent in each dataset, as shown in Table I. Based on this investigation, the proposed method takes an average of 0.13 seconds to process, has an AVG presence rate of 94.55% for keyphrases, and an AVG absence rate of 5.45% per document.

### B. Result of Curve Plotting (CP) Analysis

According to the prior discussion, since the datasets contain an average of 94.55% of keyphrases/goldkeys per document that are actually present, all results in this work have been conducted based on that percentage of goldkey. The suggested method then tries to plot the average distance of each dataset and all datasets' average values together to represent the distance between each region by considering the first occurrence keyphrase and length of documents as eight (8) regions. The proposed KDA technique analyzes keyphrase distance and is depicted in Fig. 2. This study confirms that the first region of the document, followed by the second region, and so on, has the highest average distance and most frequent keyphrases. Because the plotted curves are negatively exponential, which can be seen in Fig. 2.

### C. Result of Curve Fitting Technique (CFT)

Following the inspection of the plots, the CFT is adjusted to take into account the value of the average distance across all datasets. The suggested approach then seeks to identify the fitting curve as well as an exponential equation that is negative for that AVG distance value. Fig. 3 illustrates the analysis of the curve fitting technique in every region for the proposed KDA process while taking into account the eight regions for the documents and offers the negatively exponential curve and equation denoted in the following (4). Since this fitted curve is likewise negative exponential, as shown in Fig. 3, it is proven from this study that the highest number of keyphrases and the greatest distance are located in the 1st region of the document, then the second portion or region, and so forth.

$$y = b * e^{-cx} + d \qquad (4)$$

*where, $b = 12834.22$, $c = 1.59$, and $d = 339.30$.* Lastly, the proposed system also attempted to demonstrate the region-based keyphrase distance analysis (KDA) from news articles using curve plotting analysis as well as curve-fitting analysis.

### D. Comparison of Proposed Technique

This step involves two different kinds of comparisons, which are detailed in the next sub-subsection: comparisons to identify a superior dataset as well as comparisons to identify a superior model or technique.

*1) Comparison to Identify a Superior Dataset:* The suggested method measures the effectiveness of each dataset and identifies the best one, as shown in Table II, using evaluation criteria (such as precision, recall, and f1-score). From this
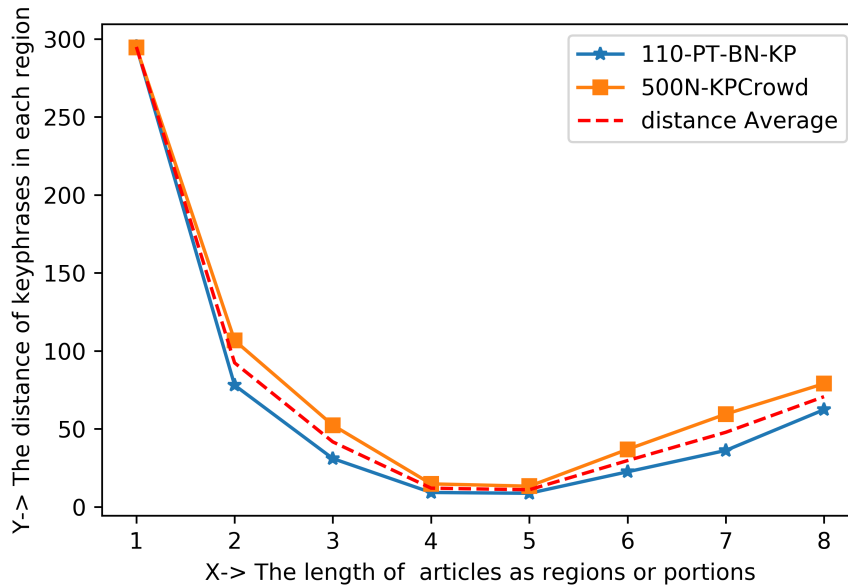
Fig. 2. The analysis of keyphrases distance by considering 1st occurrence and eight regions.
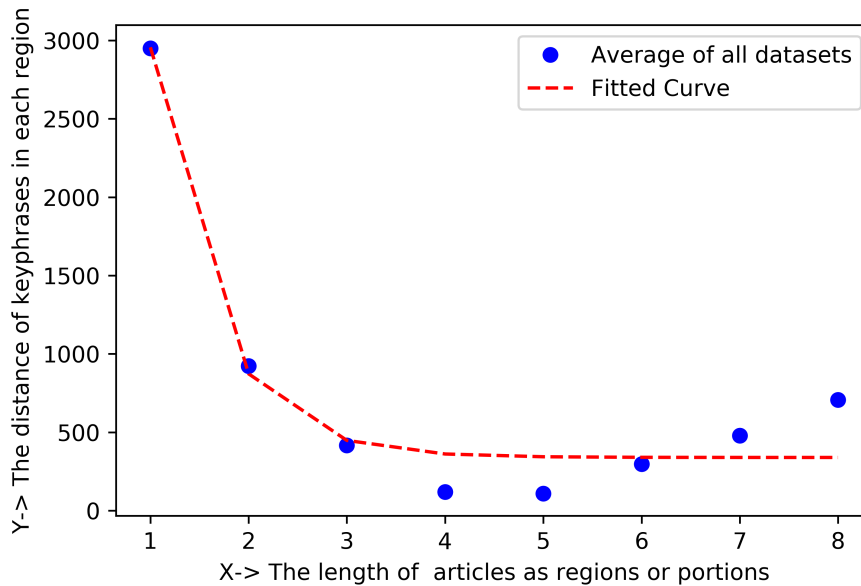


Fig. 3. The curve fitting analysis for the proposed KDA technique based on 8 regions.

table, the dataset named "110-PT-BN-KP" has a higher F1-score of 98.64% and a recall value of 97.32% than the "500N-KP-Crowd" dataset. It is indicated that the dataset "110-PT-BN-KP" performs better than the "500N-KP-Crowd" dataset.

*2) Comparison to Identify a Superior Technique:* As there is only one current method and the proposed KDA method is a novel method, it can be contrasted with the existing technique in this section. The comparison of our proposed

KDA technique is exhibited in Table III. Based on Table III, the proposed KDA technique provides a higher recall value of 94.06% and a higher F1-score of 96.91% than the existing technique. Here, the proposed approach considers average performance measurements.

## VI. CONCLUSION

In many computer science applications, feature extraction of keyphrases has now become crucial. This article proposes

TABLE II. THE DATASET'S PERFORMANCE COMPARISON FOR FINDING A BETTER ONE

| Dataset | Average Performance Measurements | | |
|---------|-----------|--------|----------|
| Name | Precision | Recall | F1_Score |
| 110-PT-BN-KP | 100% | 97.32% | 98.64% |
| 500N-KPCrowd | 100% | 90.80% | 95.18% |

TABLE III. COMPARISON OF OUR PROPOSED KDA TECHNIQUE

| Existing | Average Performance Measurements | | |
|----------|-----------|--------|----------|
| Techniques | Precision | Recall | F1_Score |
| RDAK Technique [25] | 100% | 69.31% | 80.09% |
| Proposed KDA Technique | 100% | 94.06% | 96.91% |

a region-based keyphrase distance analysis (KDA), a technique for automatic unsupervised feature extraction that is independent of domain and language and necessitates little statistical expertise and training data. Data collection, data preprocessing, data processing, searching keyphrases, distance computation, averaging distance, curve plotting, and lastly, the curve fitting technique, are the steps that make up the process of our proposed approach. After that, the KDA technique was tested and evaluated on two benchmark datasets to determine its effectiveness. Then it has produced a negative exponential equation and curve for the distance value, indicating that greater distance as well as more gold keys appear in the first region of documents. The proposed technique finally produced an accuracy/recall value of 94.06%, an F1-score of 96.91%, and a total present keyphrase of 94.55%. The proposed method also identifies *110-PT-BN-KP* as a better dataset, with a maximum recall value of 97.32% and the highest F1-score value of 98.64% than any other dataset. With the more statistical aspects given in this work, we intend to create a powerful keyphrase extraction technique in the future. The limitation of our research is that for the absent or missing keyphrase, the distance value is zero. For this reason, we are currently addressing the issue of missing goldkeys or keyphrases, such as when a large number of explicitly provided keyphrases are lacking from the document itself.

## ACKNOWLEDGMENT

## REFERENCES

[1] L. Marujo, A. Gershman, J. Carbonell, R. Frederking, and J. P. Neto, "Supervised topical key phrase extraction of news stories using crowdsourcing, light filtering and co-reference normalization," *arXiv preprint arXiv:1306.4886*, 2013.

[2] M. B. A. Miah, S. Awang, M. M. Rahman, A. S. Hosen, and I.-H. Ra, "A new unsupervised technique to analyze the centroid and frequency of keyphrases from academic articles," *Electronics*, vol. 11, no. 17, p. 2773, 2022.

[3] M. B. A. Miah, S. Awang, M. S. Azad, and M. M. Rahman, "Keyphrases concentrated area identification from academic articles as feature of keyphrase extraction: A new unsupervised approach," *International Journal of Advanced Computer Science and Applications*, vol. 13, no. 1, 2022.

[4] C. Sun, L. Hu, S. Li, T. Li, H. Li, and L. Chi, "A review of unsupervised keyphrase extraction methods using within-collection resources," *Symmetry*, vol. 12, no. 11, p. 1864, 2020.

[5] M. B. A. Miah, S. Awang, M. M. Rahman, A. S. M. Sanwar Hosen, and I.-H. Ra, "Keyphrases frequency analysis from research articles: A region-based unsupervised novel approach," *IEEE Access*, vol. 10, pp. 1–1, 2022.

[6] Y.-f. B. Wu, Q. Li, R. S. Bot, and X. Chen, "Domain-specific keyphrase extraction," in *Proceedings of the 14th ACM International Conference on Information and Knowledge Management*, 2005, pp. 283–284.

[7] U. Parida, M. Nayak, and A. K. Nayak, "Insight into diverse keyphrase extraction techniques from text documents," *Intelligent and cloud computing*, pp. 405–413, 2021.

[8] F.-S. Alotaibi, S. Sharma, V. Gupta, and S. Gupta, "Keyphrase extraction using enhanced word and document embedding," *IETE Journal of Research*, pp. 1–13, 2022.

[9] T. Tomokiyo and M. Hurst, "A language model approach to keyphrase extraction," in *Proceedings of the ACL 2003 workshop on Multiword expressions: analysis, acquisition, and treatment*, 2003, pp. 33–40.

[10] A. Dima and A. Massey, "Keyphrase extraction for technical language processing," *UMBC Faculty Collection*, 2021.

[11] K. S. Hasan and V. Ng, "Automatic keyphrase extraction: A survey of the state of the art," in *Proceedings of the 52nd Annual Meeting of the Association for Computational Linguistics (Volume 1: Long Papers)*, 2014, pp. 1262–1273.

[12] K. Bennani-Smires, C. Musat, A. Hossmann, M. Baeriswyl, and M. Jaggi, "Simple unsupervised keyphrase extraction using sentence embeddings," *arXiv preprint arXiv:1801.04470*, 2018.

[13] S. B. Kotsiantis, I. Zaharakis, and P. Pintelas, "Supervised machine learning: A review of classification techniques," *Emerging artificial intelligence applications in computer engineering*, vol. 160, no. 1, pp. 3–24, 2007.

[14] S. R. El-Beltagy and A. Rafea, "Kp-miner: A keyphrase extraction system for english and arabic documents," *Information Systems*, vol. 34, no. 1, pp. 132–144, 2009.

[15] L. Ajallouda, F. Z. Fagroud, A. Zellou, and E. B. Lahmar, "Kp-use: An unsupervised approach for key-phrases extraction from documents," *International Journal of Advanced Computer Science and Applications*, vol. 13, no. 4, 2022.

[16] R. Campos, V. Mangaravite, A. Pasquali, A. Jorge, C. Nunes, and A. Jatowt, "Yake! keyword extraction from single documents using multiple local features," *Information Sciences*, vol. 509, pp. 257–289, 2020.

[17] X. Wan and J. Xiao, "Collabrank: towards a collaborative approach to single-document keyphrase extraction," in *Proceedings of the 22nd International Conference on Computational Linguistics (Coling 2008)*, 2008, pp. 969–976.

[18] A. Bougouin, F. Boudin, and B. Daille, "Topicrank: Graph-based topic ranking for keyphrase extraction," in *International Joint Conference on natural language processing (IJCNLP)*, 2013, pp. 543–551.

[19] M. Garg and M. Kumar, "Kest: A graph-based keyphrase extraction technique for tweets summarization using markov decision process," *Expert Systems with Applications*, vol. 209, p. 118110, 2022.

[20] C. Florescu and C. Caragea, "Positionrank: An unsupervised approach to keyphrase extraction from scholarly documents," in *Proceedings of the 55th Annual Meeting of the Association for Computational Linguistics (Volume 1: Long Papers)*, 2017, pp. 1105–1115.

[21] F. Boudin, "Unsupervised keyphrase extraction with multipartite graphs," *arXiv preprint arXiv:1803.08721*, 2018.

[22] G. Rabby, S. Azad, M. Mahmud, K. Z. Zamli, and M. M. Rahman, "Teket: a tree-based unsupervised keyphrase extraction technique," *Cognitive Computation*, pp. 1–23, 2020.

[23] M. B. A. Miah and M. A. Yousuf, "Detection of lung cancer from ct image using image processing and neural network," in *2015 International Conference on Electrical Engineering and Information Communication Technology (ICEEICT)*. ieee, 2015, pp. 1–6.

[24] M. B. A. Miah and S. Awang, "Kda: An unsupervised approach for analyzing keyphrases distance from news articles as a feature of keyphrase extraction." in *The 6th National Conference for Postgraduate Research (NCON-PGR 2022)*. Universiti Malaysia Pahang, 2022, p. 83.

[25] M. B. A. Miah, S. Awang, and M. S. Azad, "Region-based distance analysis of keyphrases: A new unsupervised method for extracting keyphrases feature from articles," in *2021 International Conference on Software Engineering & Computer Systems and 4th International Conference on Computational Science and Information Management (ICSECS-ICOCSIM)*. IEEE, 2021, pp. 124–129.

[26] Z. Alami Merrouni, B. Frikh, and B. Ouhbi, "Automatic keyphrase extraction: a survey and trends," *Journal of Intelligent Information Systems*, vol. 54, no. 2, pp. 391–424, 2020.

[27] S. R. El-Beltagy and A. Rafea, "Kp-miner: Participation in semeval-2," in *Proceedings of the 5th international workshop on semantic evaluation*, 2010, pp. 190–193.

[28] N. S. M. Nafis and S. Awang, "An enhanced hybrid feature selection technique using term frequency-inverse document frequency and support vector machine-recursive feature elimination for sentiment classification," *IEEE Access*, vol. 9, pp. 52 177–52 192, 2021.

[29] K. Sarkar, M. Nasipuri, and S. Ghose, "Machine learning based keyphrase extraction: Comparing decision trees, naïve bayes, and artificial neural networks." *JIPS*, vol. 8, no. 4, pp. 693–712, 2012.

[30] M. B. A. Miah, "A real time road sign recognition using neural network," *International Journal of Computer Applications*, vol. 114, no. 13, 2015.

[31] I. H. Witten, G. W. Paynter, E. Frank, C. Gutwin, and C. G. Nevill-Manning, "Kea: Practical automated keyphrase extraction," in *Design and Usability of Digital Libraries: Case Studies in the Asia Pacific*. IGI global, 2005, pp. 129–152.

[32] O. Medelyan, E. Frank, and I. H. Witten, "Human-competitive tagging using automatic keyphrase extraction," in *Proceedings of the 2009 conference on empirical methods in natural language processing*, 2009, pp. 1318–1327.

[33] P. L. L. Romary, "Automatic key term extraction from scientific articles in grobid," in *SemEval 2010 Workshop*, 2010, p. 4.

[34] F. Bulgarov and C. Caragea, "A comparison of supervised keyphrase extraction models," in *Proceedings of the 24th international conference on World Wide Web*, 2015, pp. 13–14.

[35] F. Xie, X. Wu, and X. Zhu, "Efficient sequential pattern mining with wildcards for keyphrase extraction," *Knowledge-Based Systems*, vol. 115, pp. 27–39, 2017.

[36] R. Campos and V. Mangaravite, "Datasets of automatic keyphrase extraction," 2020. [Online]. Available: https://github.com/LIAAD/KeywordExtractor-Datasets

# Gamification in Physical Activity: State-of-the-Art

Majed Hariri[1], Richard Stone[2]

HCI Department, Iowa State University, Iowa State University, Ames, USA[1]

Industrial and Manufacturing Systems Engineering Department, Iowa State University, Ames, USA[2]

*Abstract*—Physical activity is decreasing globally, and more people are becoming sedentary, which is associated with numerous adverse health outcomes. To counter this trend, gamification emerges as a promising strategy for enhancing participation in physical activity interventions. The review investigates the influence of gamified systems on the promotion of physical activity and examines associated behavioral and psychological outcomes. The analysis incorporates empirical studies focused on adult participants, published in peer-reviewed English-language journals over the last five years. Several critical aspects are considered in the analysis, including specific types of physical activity targeted, employed gamification systems, involved motivational features, and behavioral and psychological outcomes, thus offering a state-of-the-art overview of gamification and physical activity. Findings confirm that gamification serves as an effective mechanism for promoting physical activity. To address gaps in existing research, recommendations for future work include broadening the range of metrics used for measuring physical activity and investigating the psychological benefits of gamification in physical activity interventions. Moreover, future research could benefit from leveraging addictive game design elements and utilizing artificial intelligence and computer vision models to monitor user progress and suggest appropriate challenges. In conclusion, the review outlines the considerable potential of gamification to positively affect participation in physical activity, highlighting the need for additional research to fully realize this potential.

*Keywords*—*Physical activity; gamification; gamified systems; gamification and motivation; state-of-the-art*

## I. Introduction

The increase in sedentary behaviors and lack of physical activity have significantly impacted global health, highlighting the growing problem of obesity [1]. Obesity is associated with various health risks, particularly cardiovascular problems [2]. Research has shown that weight loss can effectively reduce these cardiovascular risks [3]. Furthermore, obesity-related complications are serious and can lead to severe outcomes such as heart attacks and strokes [4]. In addition, obesity is often associated with comorbid conditions such as diabetes, a metabolic disorder that increases blood glucose levels and can lead to various complications like nerve damage, kidney failure, and vision loss [5]. Moreover, being overweight increases the likelihood of experiencing problems such as osteoarthritis [6]. There is also evidence linking obesity to various types of cancer [4]. Additionally, obese individuals are at increased risk of obstructive sleep apnea due to airway blockage caused by excess fat tissue [6]. Obese individuals have a higher incidence of depression, along with challenges in social interactions and stigma [7]. Obesity has significant implications for mental health. Moreover, obesity places a heavy burden on healthcare systems, leading to increased healthcare costs and reduced productivity in the workforce [8],

[9].

Maintaining a regular exercise routine can be challenging for many individuals despite its numerous benefits in terms of health and well-being [10]. Time constraints have been identified as one significant obstacle to consistent physical activity [10]. Another notable barrier is the concern about potential injuries during exercise, which has been emphasized [11]. Inadequate knowledge regarding effective workout strategies also contributes to inconsistent engagement in physical activity [12]. Additionally, societal pressures and cultural norms can negatively influence exercise habits [13]. Given the prevailing sedentary lifestyle prevalent today and its associated risks to health, there is an urgent need for viable solutions.

The concept of gamification offers a unique and positive approach to promoting behavioral change. By incorporating game design elements like points, rewards, and challenges, gamification enhances user engagement and motivation in non-game contexts [14]. There are mainly two ways to implement gamification. The first way is to infuse game-like features into an existing system, like incorporating a point system in physical activity programs. The second involves designing the activity as a game from scratch, which requires a more comprehensive resource commitment but offers a compelling avenue to control and manipulate the game mechanics to drive specific behaviors and outcomes. Research in various sectors has shown differing degrees of success with gamification. For instance, a study conducted on the implementation of gamification in healthcare discovered that integrating game elements into the system enhanced the collection and analysis of data, increased patient involvement and knowledge, promoted professional growth and reputation, as well as improved care for both practitioners and patients [15]. Evidence from a separate study suggests that incorporating game elements into a computer programming course can strengthen students' motivation and overall learning journey [16]. Moreover, a thorough examination of 103 existing gamified fitness tracker apps revealed promising potential for innovative approaches that seamlessly blend game mechanics in engaging and enjoyable manners instead of solely relying on conventional gamification elements and leaderboards [17]. Moreover, a research study examined the impact of gamification on users' adoption of personal finance management applications and discovered that incorporating game elements fulfilled users' desires for competence and autonomy, resulting in an increased intrinsic motivation to use gamified apps [18]. Furthermore, research on the utilization of gamification in luxury goods revealed that incorporating elements and mechanisms of game design into experiences resulted in elevated levels of brand recognition, customer loyalty, and sales [19].

Understanding the role of gamification as a tool to boost physical activity is crucial. The theoretical groundwork that guides the creation, roll-out, and evaluation of such gamified interventions falls into three main categories [20]. The first is the principle of motivation and impact, which pulls from a range of theories, including self-determination, flow, goal-setting, and self-efficacy. This principle stresses the need for developing gamified interventions tailored to the user's motivational triggers and interests. The second guiding principle focuses on behavior, drawing upon theories like activity, reinforcement, reasoned action, and planned behavior, to name a few. This aspect emphasizes the critical role of creating interventions that effectively drive behavioral outcomes. Lastly, the principle of learning incorporates theories such as experiential learning, constructivist learning, and cognitive load and highlights the importance of developing interventions that facilitate learning. A thorough examination was carried out to analyze theories related to motivation and effectiveness, providing valuable insights into the potential impact of gamification in promoting physical activity. A comprehensive evaluation was conducted on these principles and their practical implementations.

The remainder of the paper is organized as follows:

- Theoretical Background: Provides foundational theories and principles that guide the use of gamification in promoting physical activity.

- Literature Review: Dive into previous research on the subject, covering different aspects such as types of physical activity, technological platforms, and psychological outcomes, among others.

- Limitations and Shortcomings: Discusses the limitations of the review.

- Discussion: A discussion of the findings and their implications.

- Conclusion and Future Work: The key findings and suggestions for future research.

The provided framework intends to thoroughly evaluate how gamification contributes to the promotion of physical activity, pinpointing areas where current research is lacking and proposing potential future paths for exploration.

## II. THEORETICAL BACKGROUND

Gamification is a concept that draws inspiration from motivational psychology and seeks to leverage both intrinsic and extrinsic motivators. Incorporating game elements into a non-game intervention stimulates user participation in specific activities. Intrinsic motivation is driven by an individual's internal desires, such as the innate urge to explore, learn, and derive pleasure from the activity. This form of motivation enables self-regulation, as individuals are guided by their interests without needing external rewards [21]. On the other hand, extrinsic motivation is characterized by the pursuit of external rewards like financial incentives or social recognition [22]. Self-determination theory has provided valuable insights into these motivational aspects. This theory posits that the psychological needs for autonomy, competence, and relatedness are fundamental to enhancing motivation and, by

extension, well-being [23]. Within this framework, autonomy relates to individual control over actions, competence focuses on the individual's effectiveness in their pursuits, and relatedness involves feeling supported and connected to others [24], [25]. Game elements have been extensively studied in the context of gamification, offering insights into how game mechanisms can boost motivation and engagement [26], [20].

Gamification has the potential to impact users' experiences in numerous ways, with one of the most noteworthy being the flow experience [27]. Flow experience stems from psychology and refers to a mental state where individuals become fully absorbed in an activity that they lose awareness of time passing and external distractions [28]. In order to achieve a state of flow, certain conditions must be met. There needs to be an appropriate level of challenge that aligns with the individual's skill level. This balance ensures that the person remains engaged in the activity without feeling bored or overwhelmed [29]. Using gamified interventions is crucial in attaining and sustaining the state of flow. These interventions are emphasized due to the various elements present, such as points, badges, leaderboards, and challenges. Each element is designed specifically to maintain user engagement. With advancements in game engines, these interventions have evolved further by dynamically adjusting to challenge levels and providing immediate rewards. Ensuring that participants stay fully engaged and motivated throughout their experience, making the gamified intervention more enjoyable and effective [30], [31].

In the realm of gamification, game elements such as badges, progress bars, and levels are not merely decorative features but vital motivational tools. These elements serve to inspire users, compelling them to engage more deeply with the activity and work steadily towards accomplishing a goal [14], [32]. This motivational structure is intrinsically goal-oriented. It provides users with a roadmap, offering clear objectives to pursue or granting them the freedom to set their own goals [33]. The adoption of a goal-oriented approach is backed by the widely recognized goal-setting theory, which posits that specific and challenging goals can substantially improve performance and motivation [34], [35]. The goal-setting theory has been effectively deployed for over two decades to enhance outcomes in work-related tasks [33]. Several principles must be observed to maximize the effectiveness of goals within a gamified environment. Firstly, the goals should be explicit and well-defined to remove ambiguity. Secondly, they should be sufficiently challenging to engage the users. Thirdly, these goals should resonate with the users' interests or aspirations to ensure acceptance. Fourthly, continuous feedback mechanisms must be in place to keep the users informed about their progress. Lastly, an optimal level of complexity should be maintained to keep users intrigued and prevent disengagement [36]. It is important to note that game elements are routinely utilized to implement these principles effectively. For instance, badges and levels act as unmistakable indicators of progress, rewarding the user and providing motivation. Progress bars, on the other hand, offer real-time feedback, enabling users to gauge their advancement toward set objectives [37], [38].

Motivating users is a common objective in gamification, and one concept that enriches our understanding of motivation is self-efficacy [39], [40]. Self-efficacy refers to an individual's

belief in their capability to successfully complete specific tasks or achieve particular goals. This belief significantly contributes to encouraging and sustaining positive behaviors, especially within health-related contexts. When individuals have a strong sense of self-efficacy, they are more willing to take on challenges and develop strategies for overcoming them. Their confidence in their abilities inspires them to tackle complex tasks with focus and resilience, even in the face of obstacles [41]. Importantly, self-efficacy goes beyond just the skills needed for task completion; it also includes an individual's conviction in their ability to successfully perform the task [42]. The theory provides individuals with a framework for what they can potentially achieve, irrespective of their current skill level or perception [35]. Gamification often employs game elements such as levels, badges, and progress bars to foster self-efficacy. Research has shown that setting both short-term and long-term goals within a gamified system can significantly enhance an individual's self-efficacy [43]. Such game elements offer users a tangible measure of their progress, bolstering their confidence and spurring them to continue participating in the gamified experience [44].

Achievement goal theory provides essential insights into how game elements can effectively motivate users [45]. Achievement goal theory differentiates between two primary types of goal orientation: mastery-approach and performance-approach [46], [47], [48]. The former prioritizes skill development and focuses on avoiding failure, while the latter is more concerned with self-esteem and demonstrating ability relative to others, all while steering clear of perceived incompetence. By employing achievement goal theory, designers of gamified interventions can better understand and target the unique motivational needs of different users. One practical application of achievement goal theory in gamification is the customization of interventions to align with a user's specific goal orientation. Game elements such as badges, feedback, and challenges can be adapted to foster a sense of achievement, tailored to mastery or performance-approach orientations [49]. Goal customization enhances the motivational aspects of gamified experiences, making them more effective and engaging. Furthermore, understanding achievement goal theory can help recognize factors that might negatively impact intrinsic motivation [50]. For example, excessive focus on social comparison, particularly among individuals with performance-avoidance goals, can be detrimental. In such instances, gamified intervention designers often employ leaderboards and other game elements cautiously to encourage competence without fueling harmful social comparisons [50].

Social comparison theory suggests that individuals have an innate tendency to gauge their opinions and abilities by contrasting them with those of others [51]. Social comparison framework allows people to validate their perception of reality and serves as a basis for self-evaluation [52]. In the context of gamification, leaderboards serve as a practical tool that enables this form of social comparison. Leaderboards, which prominently display the performance and ranks of participants, serve as tangible representations of social comparison in gamified environments [53]. Game elements encourage individuals to evaluate or enhance specific aspects of their abilities through comparison, particularly with others they deem similar. However, the utility of leaderboards and other status-indicating elements is nuanced. Research has indicated that such features can have a dual impact: either boost or hinder motivation and performance [54], [55].

## III. Literature Review

The purpose of this literature review is to explore the potential of gamification as a tool to promote physical activity. The focus is primarily on empirical studies published in peer-reviewed journals. This exploration will shed light on the existing evidence and indicate areas that require further research.

### A. Step 1: Previous Literature

The increasing interest in gamified interventions, specifically in the context of physical activity interventions, has opened up avenues for research and academic exploration. A comprehensive study evaluated the impact of gamified interventions on physical activity and sedentary behavior [56]. Through an analysis of 16 randomized controlled trials, the results indicated that gamification had a small to medium effect on modifying physical activity behavior. These interventions were found to be more effective compared to control groups without gamified approaches. However, it was also observed that the long-term sustainability of these behavioral changes posed a challenge, as they tended to diminish over time. The study emphasized the need for standardized methodologies and further research in addressing sedentary behaviors alongside physical activity interventions.

The effectiveness of longitudinal Active Video Game interventions in maintaining increased physical activity levels was examined by [57]. Their review included 25 studies and highlighted the role of AVGs in promoting a moderate increase in overall physical activity. Consistent with previous research, their findings emphasized the inconsistencies in methodologies and called for more standardized approaches. The study also recommended further exploration of long-term effects and complexities involved in AVG interventions, indicating a need to revisit and improve research strategies.

On the other hand, another study examined the different aspects of gamification implemented in interventions and their resulting effects [58]. The research involved a thorough analysis of 16 studies, all of which emphasized the effectiveness of gamification in promoting physical activity. Key elements such as points, feedback systems, leaderboards, and challenges were found to significantly influence positive behavioral changes. However, limitations such as age group exclusions and the need for stronger research methods were identified by this study.

Another study explored the design features of gamified fitness tracker apps [59]. By examining 103 different applications, they discovered that certain game elements, such as goals, social influences, and challenges, were prevalent in these apps. However, their findings indicated that there is room for innovation by combining different game mechanics to create more captivating and impactful fitness applications.

The importance of incorporating gamification in health and well-being applications was discussed in a recent study [60]. Through a comprehensive review of 19 papers, the

researchers found that gamification does have a positive impact on health-related behaviors, but the level of empirical evidence supporting its benefits is moderate. The study calls for further high-quality research to determine the effectiveness of gamification across different outcomes.

The existing literature presents a positive yet complex depiction of gamified interventions. The clear advantages are undeniable; however, there remain uncertainties surrounding long-term effects, varying research approaches, and unexplored areas. This review aims to explore the potential of gamification in promoting physical activity by analyzing empirical studies published in peer-reviewed journals. By doing so, it offers a more nuanced interpretation of gamified interventions.

### B. Step 2: Database Search

An extensive search was carried out using the Scopus database to conduct a comprehensive search on the implementation of gamification in physical activity. The Scopus database was chosen for its reputation as a reliable source of high-quality, peer-reviewed articles covering various disciplines. A systematic and well-structured strategy was employed to filter through the Scopus database. Specific parameters revolved around gamification's influence on physical activity to ensure the search was both targeted and exhaustive. The search was conducted using keywords such as "gamif*" which encompassed variations like "gamification" and "gamified" in addition to terms like "fitness," "physical activity," and "exercise". The selection of these keywords was done diligently, ensuring a balance between including relevant studies and maintaining a strong alignment with the objective of this review.

### C. Step 3: Focused Result

The systematic search was conducted on 09/2022 and yielded 1347 records from the Scopus database. During Stage 2, this number decreased to 676 after excluding duplicates, conference papers, and books. Subsequent date restrictions were implemented in Stage 3, resulting in 338 records. In Stage 4, articles written in languages other than English were eliminated, leaving behind 212 records. During the initial screening process, titles and abstracts were carefully reviewed. At the end of Stage 5, 153 articles were excluded for various reasons, such as unavailability for download or needing to be empirical studies. As a result, there were 59 remaining records after this selection process was completed. During Stage 6, a comprehensive evaluation of the full-text documents was conducted. Forty-three articles were excluded as they needed to meet certain criteria, such as having study populations below 18 years of age or failing to adhere to the specified framework stating that motivational affordance leads to psychological and behavioral outcomes [61]. After this thorough assessment, only sixteen records remained for further consideration. In the end, only 12 records remained after excluding educational articles. These remaining articles were carefully selected to ensure that only the most relevant and reliable findings could contribute to understanding how gamification can promote physical activity. (See Fig. 1).
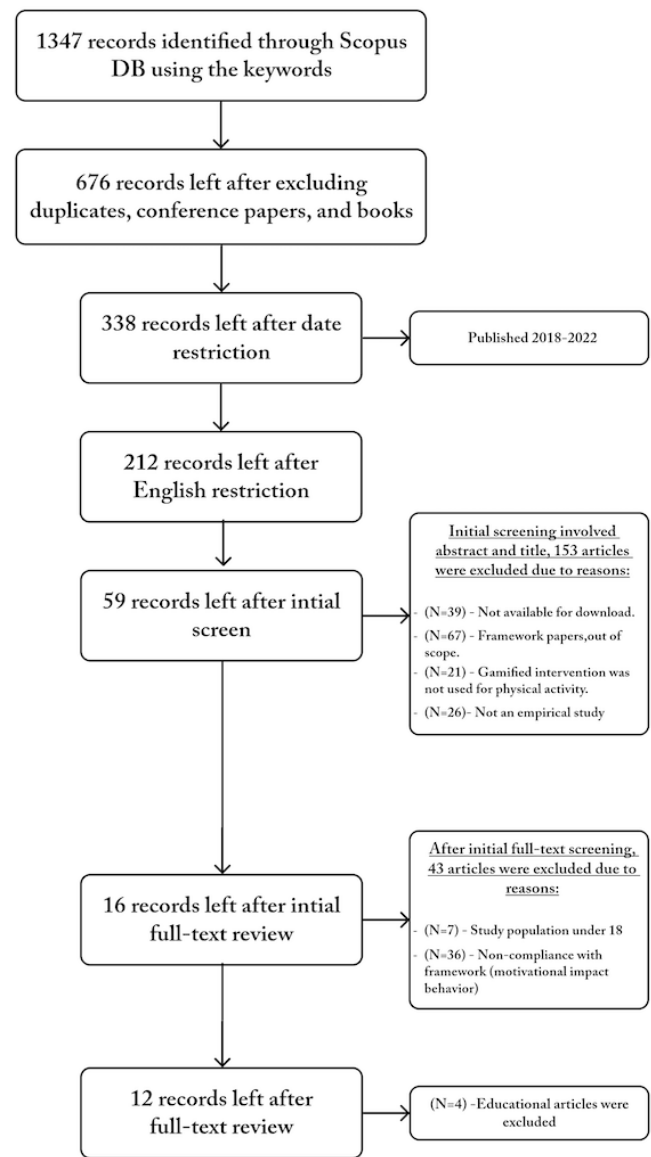


Fig. 1. Flowchart of the review process.

### D. Step 4: Analysis and Categorization

To effectively assess the impact of gamification on physical activity, this study considers six key aspects:

1) Types of Physical Activity: The analysis includes different sorts of exercises.
2) Technological Platforms: The research examines the types of technology used, such as mobile apps or wearables.
3) Motivational Elements: Key gamification elements like badges, leaderboards, and stories are given priority to find out what motivates users the most.
4) Psychological and Behavioral Outcomes: The review assesses the impact of interventions that incorporate gamification on psychological and behavioral aspects.
5) Incentive Mechanisms: Both tangible and intangible rewards are evaluated to gauge their role in user engagement.

6) *Reported Outcomes:* The review also considers the tangible results from the studies analyzed.

This focused examination helps in understanding not only the current state of the field but also offers directions for future studies.

### E. Types of Physical Activity

In the reviewed studies, walking emerged as the dominant focus, with 9 out of 12 studies aiming to boost daily step counts [62], [63], [64], [65], [66], [67], [68], [69], [70]. Other activities that have been gamified include cardio, 2 out of 12, have allowed the users to choose from a wide range of activities, such as running and swimming, which is a popular approach used in the market by companies like Fitbit and Apple [71], [72]. Finally, one study has adopted cycling as the physical activity of interest to investigate the long-term effectiveness of gamification in physical activity interventions [73] (See Fig. 2). The analyzed studies tended to rely on increasing step counts, distance traveled, and other cardio-related metrics as the main outcomes of interest. The means of collecting the data were also quite different across the studies. Some of the studies relied on in-device sensors such as accelerometers and pedometers, which are popular among the current wearables and phones. Other studies have relied on self-reported data assessed online or through a paper application.
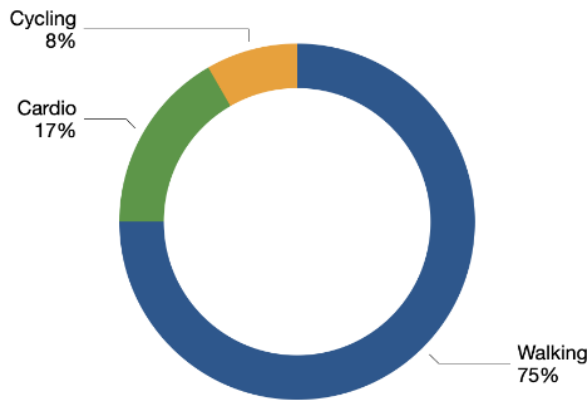


Fig. 2. Type of physical activity measured.

### F. Technological Platforms

The reviewed studies employed varying systems for gamification interventions. These systems were categorized in terms of the utilization of an existing system, such as WeChat, Playpluse, and Way to Health, to gamify physical activities. Likewise included in this category was the utilization of technology to create a new system, such as through building games or fitness trackers to promote physical activity. While the majority of the studies, 7 out of 12, have utilized the technology to create a custom system for the purpose of the study [62], [65], [66], [67], [69], [71], [72]. 5 out of 12, have utilized existing platforms and services to gamify physical activities [64], [63], [68], [70], [73]. Most of the analyzed studies utilized technology in the form of a watch as an extension of the system deployed [62], [65], [64], [63], [66], [67], [68], [71], [72], [73]. Others relied on phones to feed the system data related to the user's physical activity [69], [70](See Fig. 3). Most studies that were analyzed have created their custom system, which gave them advantages when designing the gamification interventions. It allowed them to tailor the experience to the needs of the target population. This precision maximizes motivation and engagement with the game or activity. Also, it allowed for better integration of the system with other aspects of users' lives, such as social media and work-life balance. Ultimately, it allowed for better tracking and monitoring of user data, which can provide valuable insights for researchers.
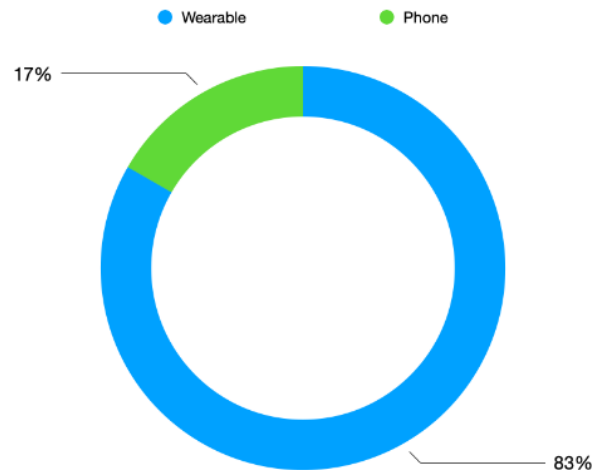


Fig. 3. System used.

### G. Motivational Elements

In the reviewed studies, points were featured in 9 out of the 12 examined studies [62], [65], [64], [63], [66], [69], [70], [71], [72]. Points are generally awarded for completing certain tasks or goals and can be redeemed for rewards. They provide a sense of progress to users and can help keep them engaged in the game or activity. The progress bar is the second most popular motivational element used in the studies. It was used in 5 out of 12 studies as a way to motivate individuals to be physically active, and within those studies, it was often paired with points or other elements [62], [69], [71], [72], [73]. The progress bar is an indicator of the percentage of completion of a task or goal. It represents how close users are to earning rewards or reaching a milestone. Challenges are the third motivational element used in the studies. It was used in 4 out of 12 studies as a mechanism to encourage

individuals to be physically active, and within those studies, it was often paired with points or other elements [62], [67], [71], [72]. Challenges are tasks or goals one must complete to gain rewards or reach milestones. Levels are the fourth motivational element used in the studies. It was found in 4 out of 12 studies to encourage physical activity [65], [64], [63], [70]. Levels are milestones one must reach by accumulating a certain number of points or completing a specific challenge (e.g., completing three tasks on Level 1 unlocks Level 2). The leaderboard is the fifth motivational element used in the studies and was found in 3 out of 12 studies as a way to encourage individuals to be physically active [62], [66], [71]. It ranks users based on their progress toward reaching certain goals or milestones. Feedback is the sixth motivational element used in the studies and was found in 3 out of 12 studies to motivate individuals to be physically active [65], [63], [70]. It is a mechanism to help users make sense of their progress and give them insight into how they can improve. Competition is the seventh motivational element used in the studies and was found in 3 out of 12 studies to motivate individuals to be physically active [63], [68], [69]. It is a technique developed to encourage users to outperform their peers by beating them at certain tasks or goals, which can be facilitated by different game elements such as leaderboards, points, and a progress bar. Rewards are the eighth motivational element used in the studies, which was found in 3 out of 12 studies to motivate individuals to be physically active[62], [68], [71]. Rewards can be tangible or intangible and can be given once a particular task, goal, or milestone is completed. They can be given for each task or goal accomplished based on cumulative points(See Fig. 4). It is worth noting that only a few studies comment on the underlying mechanism of the game elements they employed, with most focusing more on the outcomes rather than the actual design process.
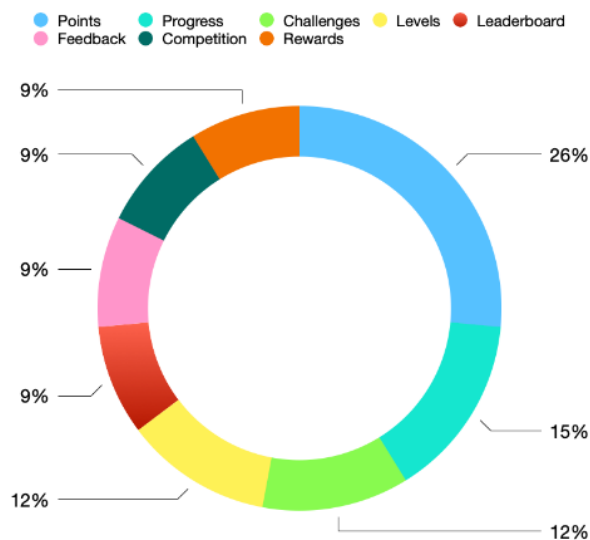


Fig. 4. Game elements used.

## H. Psychological and Behavioral Outcomes

The review also encompassed the categorization of outcomes into behavioral and psychological dimensions. Behavioral outcomes in physical activities can be easily measured with activity time, distance traveled, number of steps taken, and calories burned. These results are beneficial because they provide concrete evidence of the positive effects of the game elements on users' physical activity. Psychological outcomes are subjective outcomes that are more challenging to measure, such as users' self-esteem, level of satisfaction, improved mood, reduced stress, and self-confidence. However, they are also important outcomes because they help us determine how much users were motivated by the game elements to be active, how enjoyable it was for them, and whether or not they will continue engaging in physical activity. Overall, the studies we analyzed measured only the behavioral outcome of the game elements' effect on physical activity via various sensors such as pedometers, GPS, and accelerometers or via self-reported measures [62], [65], [64], [63], [66], [67], [68], [69], [70], [71], [72], [73]. The studies did not discuss the psychological outcomes that could provide insight into the users' attitudes and beliefs in relation to being physically active.

## I. Incentive Mechanisms

In the review studies, incentives or rewards were examined and categorized as either tangible or intangible. Tangible incentives, which consist of monetary or material rewards, were employed in 5 out of 12 studies [62], [65], [64], [69], [70]. Intangible incentives, such as points and badges, were utilized in 7 out of 12 studies [63], [66], [67], [68], [71], [72], [73]. The preponderance of intangible rewards is attributable to their lower cost and ease of implementation, as they do not necessitate additional financial resources. However, it is crucial to recognize the potential downsides of tangible rewards. Among the studies utilizing tangible rewards, 40% reported that these failed to maintain engagement in follow-up periods, while 20% did not evaluate long-term impacts. The remaining 40% observed enduring positive effects, potentially due to the intermittent provision of rewards until the study's conclusion (See Fig. 5).

## J. Reported Outcomes

The outcomes of the studies were closely reviewed, revealing that 33% of the analyzed papers focused on participants who were overweight or obese [64], [63], [66], [70]. This could be due to the fact that researchers usually use this population as a proxy for participants with low levels of physical activity, which is a limitation of the existing studies. However, this could also be explained by researchers' intentions to help people who are more likely to suffer from health problems due to their being inactive. In addition, we found that 58% of the studies did not have a follow-up period. The lack of a follow-up period is likely due to the difficulty in getting participants to return for a follow-up session. Even if researchers can get participants to complete the follow-up session, it may only be for a short period, making it difficult to discern how effective the intervention was in the long term. However, one study was the exception, which investigated the impact of their intervention over two
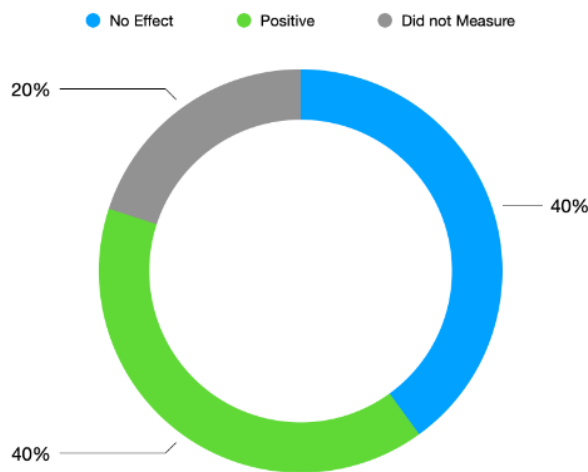
Fig. 5. Long-term effect of tangible rewards.
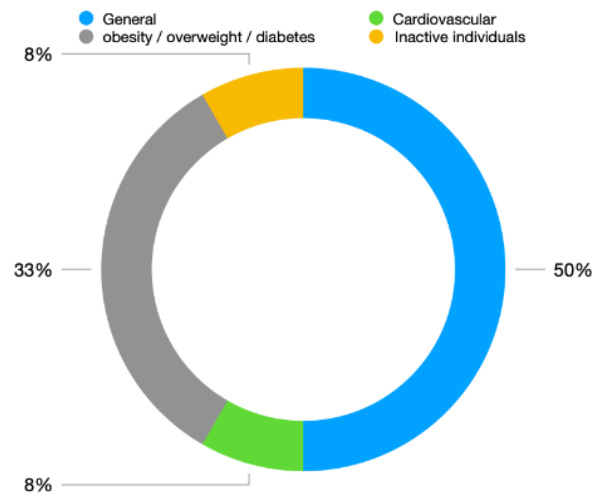


Fig. 6. Participant characteristics.

years [69]. They designed the game to have a challenge at six-week intervals, which can encourage participants to join for one interval and then stop and rejoin the next interval. Furthermore, it is critical to recognize that in the exceptional study, financial rewards were periodically given to participants to maintain the intervention's impact over an extended duration, which could clarify the intervention's sustainability(See Fig. 6). Regarding short-term, the results were classified into two categories in the analyzed studies: positive and no effects. Positive results can be determined by the game elements' effect on behavioral outcomes, whereas a lack of behavioral outcomes change indicates no effects. As reported in the 3.4 section, none of the studies measured the psychological outcomes that could provide insight into how the game elements may have influenced users' attitudes and beliefs in relation to physical activity. Therefore, we could not determine whether the psychological outcomes were positive or negative. Out of 12 studies that measured behavioral outcomes, four reported no effects [63], [70], [71], [73], and eight reported positive effects [62], [65], [64], [66], [67], [68], [69], [72]. Overall, the reported results of the studies indicate that using game elements to promote physical activity can lead to positive outcomes for participants. While some studies did not report any effects, the preponderance of evidence supports positive outcomes, indicating that this method could stimulate individuals to increase their physical activity. To ensure the long-term sustainability of physical activity interventions that incorporate game elements, researchers must measure the psychological impact of such interventions. By doing so, a better understanding of the long-term effects can be obtained, which can help maintain individuals' motivation to remain physically active over time.

## IV. Limitations and Shortcomings

In the review of the existing literature, several limitations and shortcomings in the approach become apparent. First,

the context of this review was limited to physical activity interventions incorporating gamification elements. However, the results may not be generalized to other contexts and areas. Additional reviews in varying fields like mental well-being are advised for a more comprehensive understanding of gamification's influence on physical activity. Second, due to a lack of empirical evidence, the analysis did not involve theoretical frameworks, which may help to understand the findings of this review better. Other theories and frameworks may provide further insight into how game elements influence physical activity. Third, linguistic constraints are evident as the focus was solely on English-language articles. This limitation potentially omits valuable research published in other languages. Fourth, for quality assurance, only articles from peer-reviewed journals were considered. This criterion excludes other types of scholarly work, such as reports or theses, thus narrowing the review's breadth. Fifth, the review is exclusive to studies targeting adults 18 years of age or older due to their unique psychological characteristics. Hence, the findings may not be applicable to younger demographics, including adolescents and children. Sixth, accessibility issues arise due to the utilization of articles available through Iowa State University Library's Scopus database license. Articles inaccessible through this source may exist but were excluded from the present study. Ultimately, the examination is constrained by time and focuses solely on articles that have been published in the past five years. This means that valuable older research may be disregarded despite its potential significance. Though this review has acknowledged its limitations, it serves as a foundational study that explores the potential of gamification as a tool to promote physical activity.

## V. Discussion

By analyzing the studies, the review brings forth important findings regarding various aspects such as the different types of

physical activities conducted, technological platforms utilized, motivational factors involved, psychological and behavioral results, incentive strategies employed, and reported outcomes. The review of existing literature indicates that current gamified interventions mainly concentrate on step counts as a parameter for measuring physical activity [62], [63], [64], [65], [66], [67], [68], [69], [70]. The narrow focus on step counts suggests that other types of physical activities still need to be thoroughly investigated. Although step counting is convenient, the step count approach has its limitations. The step count approach may not comprehensively assess an individual's overall activity level, particularly if step-tracking devices are not consistently used. Additionally, relying solely on step counts may not be the most effective way to achieve optimal calorie expenditure or overall health benefits through exercise. Accordingly, the reviewed studies revealed that technological platforms can influence the effectiveness of gamification interventions. The reviewed studies have shown a preference for wearable devices over smartphones in the gamified interventions [62], [65], [64], [63], [66], [67], [68], [71], [72], [73]. While the findings overall were positive, highlighting the effectiveness of game elements in short-term physical activity promotion, they were not without limitations. Moreover, to effectively promote long-term physical activity, it is crucial to have a comprehensive understanding of the psychological processes underlying behavioral metrics. Furthermore, It is worth noting that while tangible rewards can be effective in motivating individuals, they also have the potential to negatively impact intrinsic motivation over time. Therefore, gamified interventions should carefully consider a balanced approach. Lastly, although the reviewed studies did not incorporate advanced technologies such as artificial intelligence or machine learning models, their integration could provide promising opportunities to personalize gamification features. By using artificial intelligence or machine learning models, dynamic and personalized challenges could be created, resulting in increased user engagement and overall effectiveness of the gamified intervention.

## VI. Conclusion and Future Work

The current state of gamification within physical activity interventions is still in its nascent stages, and further development is necessary. The existing literature reveals limitations, especially when relying on constant positive reinforcement and motivation. Such strategies eventually deplete the will to continue and blunt sensitivity to rewards. To create more sustainable interventions, learning from digital game design is essential, particularly regarding reward systems. Emphasis should also be on the strategic deployment of both positive and negative feedback mechanisms to sustain user engagement. The future of this field could benefit greatly from the incorporation of artificial intelligence and computer vision models, not only for optimizing difficulty and rewards but also for tracking various metrics. In terms of the types of physical activities considered, most studies primarily target metrics related to cardio exercises like step counts and distance traveled. These studies often employ in-device sensors, such as accelerometers and pedometers, or rely on self-reported data collected either online or via paper applications. This suggests an opportunity for broadening the scope of research to include activities like weightlifting and

other forms of resistance training using a computer vision model to monitor the progress. Moreover, the studies largely bypass any discussion of psychological outcomes. Attitudinal and belief systems related to physical activity offer invaluable insights and should be incorporated into future research efforts. These metrics can help inform the creation of interventions that are not only physically effective but also psychologically motivating.

## Disclosure of interest

The authors report there are no competing interests to declare.

## References

[1] R. Guthold, G. A. Stevens, L. M. Riley, and F. C. Bull, "Global trends in insufficient physical activity among adolescents: a pooled analysis of 298 population-based surveys with 1·6 million participants," *The Lancet Child and Adolescent Health*, vol. 4, no. 1, pp. 23–35, 1 2020.

[2] M. F. F. Lopes, "Obesity and Related Diseases," in *Gastric Bypass*. Springer International Publishing, 2020, pp. 31–40.

[3] C. J. Lavie, R. V. Milani, and H. O. Ventura, "Obesity and Cardiovascular Disease. Risk Factor, Paradox, and Impact of Weight Loss," pp. 1925–1932, 5 2009.

[4] D. P. Guh, W. Zhang, N. Bansback, Z. Amarsi, C. L. Birmingham, and A. H. Anis, "The incidence of co-morbidities related to obesity and overweight: A systematic review and meta-analysis," *BMC Public Health*, vol. 9, 2009.

[5] T. W. Strine, A. H. Mokdad, S. R. Dube, L. S. Balluz, O. Gonzalez, J. T. Berry, R. Manderscheid, and K. Kroenke, "The association of depression and anxiety with obesity and unhealthy behaviors among community-dwelling US adults," *General Hospital Psychiatry*, vol. 30, no. 2, pp. 127–137, 3 2008.

[6] K. M. Carpenter, D. S. Hasin, D. B. Allison, and M. S. Faith, "A B S T R A C T Relationships Between Obesity and DSM-IV Major Depressive Disorder, Suicide Ideation, and Suicide Attempts: Results From a General Population Study," Tech. Rep. 2, 2000.

[7] A. J. Stunkard, M. S. Faith, and K. C. Allison, "Depression and obesity," pp. 330–337, 8 2003.

[8] Y. Wang, M. A. Beydoun, L. Liang, B. Caballero, and S. K. Kumanyika, "Will all Americans become overweight or obese? Estimating the progression and cost of the US obesity epidemic," *Obesity*, vol. 16, no. 10, pp. 2323–2330, 10 2008.

[9] D. D. Kim and A. Basu, "Estimating the Medical Care Costs of Obesity in the United States: Systematic Review, Meta-Analysis, and Empirical Analysis," pp. 602–613, 7 2016.

[10] C. J. Barton, M. G. King, B. Dascombe, N. F. Taylor, D. de Oliveira Silva, S. Holden, A. J. Goff, K. Takarangi, and N. Shields, "Many physiotherapists lack preparedness to prescribe physical activity and exercise to people with musculoskeletal pain: A multi-national survey," *Physical Therapy in Sport*, vol. 49, pp. 98–105, 5 2021.

[11] A. G. Huebschmann, L. A. Crane, E. S. Belansky, S. Scarbro, J. A. Marshall, and J. G. Regensteiner, "Fear of injury with physical activity is greater in adults with diabetes than in adults without diabetes," *Diabetes Care*, vol. 34, no. 8, pp. 1717–1722, 8 2011.

[12] E. Hoare, B. Stavreski, G. L. Jennings, and B. A. Kingwell, "Exploring motivation and barriers to physical activity among active and inactive australian adults," *Sports*, vol. 5, no. 3, 9 2017.

[13] S. Dixit, S. P. Singh, P. Kariwala, A. K. Singh, and S. Dutt Kandpal, "Barriers to being physically active: An exploratory study among medical students," *Indian Journal of Forensic and Community Medicine*, vol. 8, no. 2, pp. 109–114, 7 2021.

[14] Deterding, Sebastian and Dixon, Dan and Khaled, Rilla and Nacke, and Lennart, "From game design elements to gamefulness: defining" gamification"," *Proceedings of the 15th International Academic MindTrek Conference Envisioning Future Media Environments*, p. 341, 2011.

[15] I. Wallenburg and R. Bal, "The gaming healthcare practitioner: How practices of datafication and gamification reconfigure care," *Health Informatics Journal*, vol. 25, no. 3, pp. 549–557, 9 2019.

[16] C. Pilkington, "A Playful Approach to Fostering Motivation in a Distance Education Computer Programming Course: Behaviour Change and Student Perceptions," Tech. Rep., 2018.

[17] A. Neupane, D. Hansen, A. Sharma, J. A. Fails, B. Neupane, and J. Beutler, "A Review of Gamified Fitness Tracker Apps and Future Directions," in *CHI PLAY 2020 - Proceedings of the Annual Symposium on Computer-Human Interaction in Play*. Association for Computing Machinery, Inc, 11 2020, pp. 522–533.

[18] P. Bitrián, I. Buil, and S. Catalán, "Making finance fun: the gamification of personal financial management apps," *International Journal of Bank Marketing*, vol. 39, no. 7, pp. 1310–1332, 10 2021.

[19] M. Milanesi, S. Guercini, and A. Runfola, "Lets play! Gamification as a marketing tool to deliver a digital luxury experience," *Electronic Commerce Research*, 2022.

[20] J. Krath, L. Schürmann, and H. F. von Korflesch, "Revealing the theoretical basis of gamification: A systematic review and analysis of theory in research on gamification, serious games and game-based learning," *Computers in Human Behavior*, vol. 125, 12 2021.

[21] L. Legault and M. Inzlicht, "Self-Determination, Self-Regulation, and the Brain: Autonomy Improves Performance by Enhancing Neuroaffective Responsiveness to Self-Regulation Failure," *Journal of Personality and Social Psychology*, vol. 105, no. 1, pp. 123–138, 7 2013.

[22] Irving B. Weiner and W. Edward Craighead., "SELF-DETERMINATION," *The Corsini Encyclopedia of Psychology*, 2009.

[23] R. M. Ryan and E. L. Deci, "Self-Determination Theory and the Facilitation of Intrinsic Motivation, Social Development, and Well-Being Self-Determination Theory," Tech. Rep., 1985.

[24] L. Legault, "Self-Determination Theory," in *Encyclopedia of Personality and Individual Differences*. Cham: Springer International Publishing, 2017, pp. 1–9. [Online]. Available: http://link.springer.com/10.1007/978-3-319-28099-8_1162-1

[25] M. Sailer, J. U. Hense, S. K. Mayr, and H. Mandl, "How gamification motivates: An experimental study of the effects of specific game design elements on psychological need satisfaction," *Computers in Human Behavior*, vol. 69, pp. 371–380, 4 2017.

[26] A. Cardoso, G. R. Alves, T. Restivo, IEEE Education Society, and Institute of Electrical and Electronics Engineers, "Gamification in STEM programming courses," in *2020 IEEE Global Engineering Education Conference (EDUCON)*, 2020, pp. 859–866.

[27] W. Oliveira, A. Toda, P. Toledo, L. Shi, J. Vassileva, I. I. Bittencourt, and S. Isotani, "Does Tailoring Gamified Educational Systems Matter? The Impact on Students' Flow Experience," 2020. [Online]. Available: https://hdl.handle.net/10125/63891

[28] M. Csikszentmihalyi and I. Csikszentmihalyi, *Beyond boredom and anxiety*, Jossey-Bass San Francisco, 1975, vol. volume 721.

[29] M. Csikszentmihalyi and I. Csikszentmihalyi, *Optimal Experience*, M. Csikszentmihalyi and I. S. Csikszentmihalyi, Eds. Cambridge University Press, 8 1988.

[30] S. Kim, "How a company's gamification strategy influences corporate learning: A study based on gamified MSLP (Mobile social learning platform)," *Telematics and Informatics*, vol. 57, 3 2021.

[31] S. Prasad, U. Kasi, and R. Shivakumar, "A Comprehensive Analysis and Design of Addictive Educational Mobile Games," Tech. Rep. 36, 2020.

[32] K. Huotari and J. Hamari, "A definition for gamification: anchoring gamification in the service marketing literature," *Electronic Markets*, vol. 27, no. 1, pp. 21–31, 2 2017.

[33] G. F. Tondello, H. Premsukh, and L. E. Nacke, "A theory of gamification principles through goal-setting theory," in *Proceedings of the Annual Hawaii International Conference on System Sciences*, vol. 2018-January. IEEE Computer Society, 2018, pp. 1118–1127.

[34] E. A. Locke, *New Developments in Goal Setting and Task Performance*, 1st ed. Routledge, 1 2013. [Online]. Available: https://www.taylorfrancis.com/books/9780203082744

[35] E. A. Locke and G. P. Latham, "Building a practically useful theory of goal setting and task motivation: A 35-year odyssey." *American Psychologist*, vol. 57, no. 9, pp. 705–717, 9 2002. [Online]. Available: http://doi.apa.org/getdoi.cfm?doi=10.1037/0003-066X.57.9.705

[36] H. L. Tosi, E. A. Locke, and G. P. Latham, "A Theory of Goal Setting and Task Performance," *The Academy of Management Review*, vol. 16, no. 2, p. 480, 4 1991.

[37] S. H. Hsu, J. W. Chang, and C. C. Lee, "Designing attractive gamification features for collaborative storytelling websites," *Cyberpsychology, Behavior, and Social Networking*, vol. 16, no. 6, pp. 428–435, 6 2013.

[38] D. S. Tan, B. Begole, W. Kellogg, and SIGCHI (Group : U.S.), *Proceedings of the 2011 annual conference extended abstracts on Human factors in computing systems : 2011 proceeding, Vancouver, BC, Canada - May 07-12, 2011*. ACM Press, 2011.

[39] A. Bandura, "Social foundations of thought and action," *Englewood Cliffs, NJ*, vol. 1986, pp. 23–28, 1986.

[40] ——, "Self-efficacy: Toward a Unifying Theory of Behavioral Change," Tech. Rep. 2, 1977.

[41] M. Ross, H. Perkins, and K. Bodey, "Academic motivation and information literacy self-efficacy: The importance of a simple desire to know," *Library and Information Science Research*, vol. 38, no. 1, pp. 2–9, 1 2016.

[42] Tanya Tandon, "A Study on Relationship between Self Efficacy and Flow at Work among Young Adults," *International Journal of Indian Psychology*, vol. 4, no. 4, 8 2017.

[43] Landers, Richard N and Bauer, Kristina N and Callan, Rachel C and Armstrong, and Michael B, "Psychological theory and the gamification of learning," *Gamification in education and business*, pp. 165–186, 2015.

[44] J. Buckworth, "Promoting Self-Efficacy for Healthy Behaviors," Tech. Rep. [Online]. Available: www.acsm-healthfitness.org

[45] J. Hamari and V. Eranti, "Framework for Designing and Evaluating Game Achievements," Tech. Rep., 2011.

[46] J. G. Nicholls, "Achievement Motivation: Conceptions of Ability, Subjective Experience, Task Choice, and Performance," Tech. Rep. 3, 1984.

[47] A. J. Elliot and H. A. Mcgregor, "A 2 X 2 Achievement Goal Framework," *Journal of Personality and Social Psychology*, vol. 80, no. 3, pp. 50–519, 2001.

[48] P. R. Pintrich, E. Ander-man, A. Danos Elder, T. Garcia, L. Hicks Anderman, B. Hofer, H. Patrick, A. Ryan, T. Urdan, C. Wolters, and S. Yu, "Multiple Goals, Multiple Pathways: The Role of Goal Orientation in Learning and Achievement have shown that," *Journal of Educational Psychology*, vol. 92, no. 3, pp. 544–555, 2000.

[49] F. Roosta, F. Taghiyareh, and M. Mosharraf, "Personalization of gamification-elements in an e-learning environment based on learners' motivation," in *2016 8th International Symposium on Telecommunications, IST 2016*. Institute of Electrical and Electronics Engineers Inc., 3 2017, pp. 637–642.

[50] T. B. Durmaz, J. L. Fuertes, and R. Imbert, "Toward Usability Testing of Motivational Affordances through Gamification," *International Journal of Human-Computer Interaction*, 2022.

[51] L. Festinger, "A Theory of Social Comparison Processes," *Human Relations*, vol. 7, no. 2, pp. 117–140, 1954.

[52] D. H. Wedell and A. Parducci, "Social Comparison," in *Handbook of Social Comparison*. Boston, MA: Springer US, 2000, pp. 223–252.

[53] J. Vassileva, "Motivating participation in social computing applications: A user modeling perspective," pp. 177–201, 4 2012.

[54] J. Bayuk and S. A. Altobello, "Can gamification improve financial behavior? The moderating role of app expertise," *International Journal of Bank Marketing*, vol. 37, no. 4, pp. 951–975, 6 2019.

[55] K. R. Christy and J. Fox, "Leaderboards in a virtual classroom: A test of stereotype threat and social comparison explanations for women's math performance," *Computers & Education*, vol. 78, pp. 66–77, 9 2014.

[56] A. Mazeas, M. Duclos, B. Pereira, and A. Chalabaev, "Evaluating the effectiveness of gamification on physical activity: systematic review and meta-analysis of randomized controlled trials," *Journal of medical Internet research*, vol. 24, no. 1, p. e26779, 2022.

[57] A. C. Moller, C. V. Sousa, K. J. Lee, D. Alon, and A. S. Lu, "Active video game interventions targeting physical activity behaviors: Systematic review and meta-analysis," *Journal of Medical Internet Research*, vol. 25, p. e45243, 2023.

[58] J. Koivisto and J. Hamari, "Gamification of physical activity: A systematic literature review of comparison studies," in *3rd International GamiFIN Conference, GamiFIN 2019*. CEUR-WS, 2019.

[59] A. Neupane, D. Hansen, A. Sharma, J. A. Fails, B. Neupane, and J. Beutler, "A review of gamified fitness tracker apps and future directions," in *Proceedings of the Annual Symposium on Computer-Human Interaction in Play*, 2020, pp. 522–533.

[60] D. Johnson, S. Deterding, K.-A. Kuhn, A. Staneva, S. Stoyanov, and L. Hides, "Gamification for health and wellbeing: A systematic review of the literature," *Internet interventions*, vol. 6, pp. 89–106, 2016.

[61] J. Hamari, J. Koivisto, and H. Sarsa, "Does gamification work? - A literature review of empirical studies on gamification," in *Proceedings of the Annual Hawaii International Conference on System Sciences*. IEEE Computer Society, 2014, pp. 3025–3034.

[62] R. Nuijten, P. Van Gorp, A. Khanshan, P. Le Blanc, A. Kemperman, P. van den Berg, and M. Simons, "Health promotion through monetary incentives: Evaluating the impact of different reinforcement schedules on engagement levels with a mhealth app," *Electronics (Switzerland)*, vol. 10, no. 23, 12 2021.

[63] M. S. Patel, D. S. Small, J. D. Harrison, V. Hilbert, M. P. Fortunato, A. L. Oon, C. A. Rareshide, and K. G. Volpp, "Effect of Behaviorally Designed Gamification with Social Incentives on Lifestyle Modification among Adults with Uncontrolled Diabetes: A Randomized Clinical Trial," *JAMA Network Open*, 2021.

[64] A. K. Agarwal, K. J. Waddell, D. S. Small, C. Evans, T. O. Harrington, R. Djaraher, A. L. Oon, and M. S. Patel, "Effect of Gamification with and without Financial Incentives to Increase Physical Activity among Veterans Classified as Having Obesity or Overweight: A Randomized Clinical Trial," *JAMA Network Open*, vol. 4, no. 7, 7 2021.

[65] M. S. Patel, C. Bachireddy, D. S. Small, J. D. Harrison, T. O. Harrington, A. L. Oon, C. A. Rareshide, C. K. Snider, and K. G. Volpp,
"Effect of Goal-Setting Approaches within a Gamification Intervention to Increase Physical Activity among Economically Disadvantaged Adults at Elevated Risk for Major Adverse Cardiovascular Events: The ENGAGE Randomized Clinical Trial," *JAMA Cardiology*, vol. 6, no. 12, pp. 1387–1396, 12 2021.

[66] X. S. Chen, S. Changolkar, A. S. Navathe, K. A. Linn, G. Reh, G. Szwartz, D. Steier, S. Godby, M. Balachandran, J. D. Harrison, C. A. Rareshide, and M. S. Patel, "Association between behavioral phenotypes and response to a physical activity intervention using gamification and social incentives: Secondary analysis of the STEP up randomized clinical trial," *PLoS ONE*, vol. 15, no. 10 October, 10 2020.

[67] L. M. Lier and C. Breuer, "The motivating power of gamification: Does the inclusion of game elements increase the effectiveness of worksite health promotion programs?" *International Journal of Workplace Health Management*, vol. 13, no. 1, pp. 1–15, 1 2020.

[68] D. Mo, M. Xiang, M. Luo, Y. Dong, Y. Fang, S. Zhang, Z. Zhang, and H. Liang, "Using gamification and social incentives to increase physical activity and related social cognition among undergraduate students in Shanghai, China," *International Journal of Environmental Research and Public Health*, vol. 16, no. 5, 3 2019.

[69] M. A. Harris, "Maintenance of behaviour change following a community-wide gamification based physical activity intervention," *Preventive Medicine Reports*, vol. 13, pp. 37–40, 3 2019.

[70] G. W. Kurtzman, S. C. Day, D. S. Small, M. Lynch, J. Zhu, W. Wang, C. A. Rareshide, and M. S. Patel, "Social Incentives and Gamification to Promote Weight Loss: The LOSE IT Randomized, Controlled Trial," *Journal of General Internal Medicine*, vol. 33, no. 10, pp. 1669–1675, 10 2018.

[71] R. Nuijten, P. Van Gorp, A. Khanshan, P. Le Blanc, P. van den Berg, A. Kemperman, and M. Simons, "Evaluating the Impact of Adaptive Personalized Goal Setting on Engagement Levels of Government Staff With a Gamified mHealth Tool: Results From a 2-Month Randomized Controlled Trial," *JMIR mHealth and uHealth*, vol. 10, no. 3, 3 2022.

[72] Z. Zhao, A. Arya, R. Orji, and G. Chan, "Effects of a personalized fitness recommender system using gamification and continuous player modeling: System design and long-term validation study," *JMIR Serious Games*, vol. 8, no. 4, 10 2020.

[73] J. Berg, A. I. Wang, S. Lydersen, and T. Moholdt, "Can Gaming Get You Fit?" *Frontiers in Physiology*, vol. 11, 8 2020.

# Investigate the Impact of Stemming on Mauritanian Dialect Classification using Machine Learning Techniques

Mohamed El Moustapha El Arby CHRIF[1], Cheikhane Seyed[2], Cheikhne Mohamed Mahmoud[3]
EL BENANY Mohamed Mahmoud[4], Fatimetou Mint Mohamed-Saleck[5], Moustapha Mohamed Saleck[6]
Omar EL BEQQALI[7], Mohamedade Farouk NANNE[8]
Department of Mathematics and Computer Science, Nouakchott University, Nouakchott, Mauritania[1,3,4,5,6,8]
Higher School of Polytechnic of Dakar, University Cheikh Anta Diop, Dakar, Senegal[2]
Department of Computer Science, University Sidi Mohamed Ben Abdallah, Fes, Maroc[7]

*Abstract*—Despite the plethora and diversity of research on Natural Language Processing (NLP). As a technique allowing computers to understand, generate, and manipulate human language; It still remains insufficient, especially with regard to the processing of Arabic texts and their dialects which are widely used. The proposed approach focuses on the application of machine learning techniques taking into account evaluation criteria such as training to comments expressed in Mauritanian dialect, published on social media notably Facebook, and compares results generated by three algorithms which we applied such as the Random Forest (RF), Naïve Bayes Multinominal (NBM), and Logistic Regression (LR) algorithm. Additionally, We then study the effect of machine learning techniques when different stemmers are combined with other features such as the tokenizers used to process the dataset. Although major challenges exist such as the morphology of Arabic is completely different from Latin letter languages, and there is no pre-existing dataset or dictionary to train the algorithms, the result we obtained after the experiments carried out on Weka shows that the RF and NBM algorithms are more efficient when applied with ArbicStemmerKhoja giving results respectively 96.37% and 71.40%; However, Logistic gets better performance results with Null Stemme is 81.65%. Results obtained by the three techniques applied with a light Arabic stemmer were more than 70%. This article presents a contribution to NLP based on Machine learning, descript also an important study that can determine the best Arabic classifier.*

*Keywords*—*Machine learning; Natural Language Processing; Arabic text classification; HASSANIYA dialect; Weka; stemming*

## I. INTRODUCTION

Mauritania, like other countries around the world, has been invaded by new technology, which has given rise to exchange platforms commonly known as social media, through which inter-family exchanges on the one hand, and inter-governmental and two-way exchanges between government agencies and the public (citizens) on the other, can take place. Thereafter a data stream in dialect Mauritania and Arabic language will be generated reflecting the citizens' sentiment. Whereas, Sentiment analysis is an approach that uses natural language processing (NLP) [1], machine learning analysis methods [2] [3], or other lexicon-based methods [4] to extract, convert, and interpret opinions from a text and classify them into positive, negative, or neutral sentiments. However, the emergence of new technologies will allow governments and companies to take into account the opinions of their public via social media, which would help them make better decisions. Thus, artificial intelligence (AI) within other technologies has solved the challenges of business practice and introduced the application of Business Intelligence (BI) that has promoted the transformation of information. In this sense, several processing techniques have been used to classify large volumes of data (Big Data) for example regression analysis, Naïve Bayes (NB), Support Vector Machine (SVM), and Neural Network (NN) [5]. So far, most research work has been done to classify text using Machine Learning for various languages like English more than Arabic sometimes when Arabic native speakers are more than non-Arabic according to [4].

We consider dialectal Arabic to be a new field of research in the field of text classification, for several reasons: firstly, dialect is widely used in social networks, which generates a large amount of data; secondly, dialect, whether HASSANIYA or others, is generally more widely used than the main language, even if this is not an official case. Moreover, the Mauritanian dialect has an alphabet and script that are those of Arabic, which means that dialect has become an important area of research; Regarding the complexity of HAASANIYA, justified by the reasons listed above, in this work, we propose an approach that gives a clear view of the classification of HASSANIYA text using machine learning algorithms and comparing the archived result. To implement the proposed approach, we use WAKE, which implements several filters and classifiers from machine learning algorithms [6].

The differences between Standard Arabic and dialectal Arabic are minimal in terms of derivation and grammar, as well as termination. On this basis, we decided to study the classification of Mauritanian dialectal texts taking into account the effect of the stemmer method. The goal of this work is to identify the best Machine Learning for dialect classification and the effect of stemming and tokenization on text classification, particularly the HASSANIYA dialect; nevertheless, we fusion deference filters for building our property models.

More specifically, a HASSANIYA dataset was collected on Facebook and contains comments posted on popular pages in Mauritania such as bloggers' pages or government pages (the Ministry of Hydraulics, the Ministry of the Interior and Decentralization, Ministry of Housing and Urban Development) that

we prepared in order to prove the stemmer method on dialectal text. To experiment, three types of stemmer were adopted in this work such as light stemming, null stemming, and heavy stemming in this case we use khoja, and every one of these three types is fusionned with another filter to make a new method. We tested three Machine Learning algorithms individually on the models built mentioned above. Machine Learning techniques applied are NVM, RF, and logistic regression.

The main contributions of this paper are:

- scraping data from Facebook pages to build a HAS-SANIYA dialect dataset;
- proving the classification of the HASSANIYA dialect text with Machine Learning techniques;
- applying and comparing different types of Stemmer to improve text classification.

The paper is organized as follows: an introduction followed by a state of the art and literature review gives an overview of the Arabic language and its dialects, then we explain our research methodologies followed in this paper and finally, we discuss the results obtained and give a conclusion.

## II. Related Works

Text classification presents an amazing field in the data analysis area, and still rich in terms of scientific research, increasing domain due to what we let know. Many researchers studied these cases and realized more articles, but the Arabic language and its dialects still need more work.

In this context, several studies have been carried out such as the approach [4] gives an approach for the classification of Arabic texts using various algorithms, and showed an enhancement in the accuracy of classifier models.

Authors in the article [7] explored a comparative system on two different datasets based on the machine learning technique, classification models are compared in terms of accuracy for each dataset.

Another study [8] applied six variations of the Bayes classifier on Arabic data, after analyzing their results were compared, and showed that the best values were generated successively from Naïve Bayes and Naïve Baye Update, in another way Naïve Bayes Multinomial Text generated the worst results.

Proposed [9] a contribution to big data processing which is considered a challenging stage of data analysis ax, so a solution proved for the challenges in four stages: data collection, cleaning, enrichment, and availability. they looked to convert social media data to computation-based data after it was source-based.

The author [10] Proposed a model for text dialectal classification, they prepared a dataset of Marocain dialect scraped from Twitter comments and a combination of extraction(n-grames), weighting schema(Bow, TF-IDF), and word embedding was applied in order to prove the Marocain dialect classification and get the best classify model. the Machine Learning techniques which they applied are following: Naive Bayes, Random Fest, support Vector Machine, Logistic Regression, and a Deep Learning Model such as Long Short term

Memory (LSTM). the experimental work showed that the SVM achieved an accuracy equal to 70%.

This paper [11] proposed a new algorithm to generate all potential derivation roots of an Arabic word, without deleting initial affixes. the author seeks to address the weaknesses and errors of existing algorithms in order to improve the accuracy of Arabic Natural language Processing. they used in this study a data set that includes a collection of roots, patterns, and affixes. by matching the derived word to identify the root. and then, they get an average accuracy rate of 96%.

This study [12] proposed a model as a novel assembly of CNNs for analysis of the task of Arabic dialect classification from spontaneous Arabic speech dataset. this model is based on a fusion of linguistic and acoustic features and uses pre-trained bidirectional encoder representation from the transformed (BERT) Model. the proposed approach achieves an accuracy of 82.44% for the identification task of five Arabic dialects.

The author [13] proposes an approach to improve P-Stemmer by combining it with various classifiers such as Naïve Bayes, Random Forest, Support Vector Machines, K-Nearest Neighbor, and K-Star. In this study they used a data set synthesized from various online news pages and did the experience on Weka tools, which is achieving the result showed that the P stemmer has Improved when using NB.

## III. Review of Arabic and its Dialects

Arabic is one of the major languages used in the world, it is used by all Muslims because is the language of the holy book of Islam [6], [14], as well, Arabic divided into three categories according to [14] as follows: First, Classical Arabic (CA) is considered the oldest type it is the Arabic literature, The Holy Quran; Second, Modern Standard Arabic (MSA) can be defined as a simplified version of Classical Arabic to be comprehensible by whole people and be became largely used; and then, exists a third type called Arabic Dialect use the same Arabic characters for writing, this one used more than two above types in daily life.
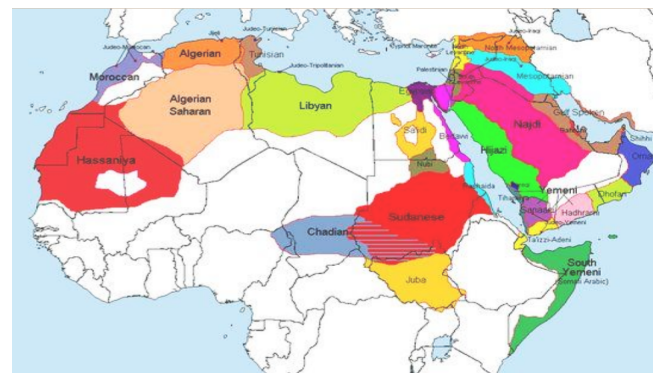


Fig. 1. Arabic dialect Map.

The Arabic dialect is divided into several types, as shown in Fig. 1; for instance:

- Moroccan Dialect: The Moroccan dialect commonly Diarj [10];

- Egyptian Dialect: The Egyptian dialect is spoken in Egypt;
- North African Dialect: The North African dialect is spoken in Algeria, Libya, and Morocco [12];
- Tunisian Dialect: Tunisian [15], and others are also Arabic dialects [16];
- Mauritania Dialect: This is named HISSANIYA dialect and is spoken mainly in the middle Mougreb region, more specifically in Mauritania country.

*Mauritania Dialect:* The Mauritanian dialect named HASSANIYA is a local dialect and a variety of Maghrebi Arabic spoken by Mauritanian Arabs widely used in daily life not only to change between families but also to indicate or share feelings and opinions on social media and to interact with others' posts. The operation of HASSANIYA text classification is becoming increasingly complicated, for three reasons: firstly, HASSINIYA is an Arabic dialect that has the same letters of the alphabet for writing, with changes in pronunciation and meaning depending on their diacritics, and ambiguity between words' root and their derivation; secondly, it is an unstructured language; thirdly, there is no data set or dictionary pre-exists.

In Table I, we segment an example of a Hassaniya word into sub-segments that show its basic construction; as mentioned above, this dialect uses Arabic letters and can be conjugated with all subjects and tenses; as shown in the following table, the word HISSANIYA has an affix such as prefix, suffix, and postfix determined by usage.

TABLE I. EXAMPLE OF A HASSANIYA « ماخَلَّيْتُو » WORD WHICH HAS DIFFERENT AFFIXES ATTACHED TO A ROOT WORD

| Word | تُو | يْ | خَلَّ | ما |
|---|---|---|---|---|
| Meaning | Pronoun '' You '' | Termination of conjugation | let | Negation like "Don't" |
| Affixes | Postfix | Suffix | Root | Prefix |

## IV. MATERIALS AND METHODS

The main stages in our proposed Methodology are data collection, preprocessing, building technique, classification, and Evaluation stages will be described in the following. This approach was applied using Weka tools. For the sake of a better selection of dialectal words, we adopt in this work a methodology consisting of phases shown in Fig. 2.
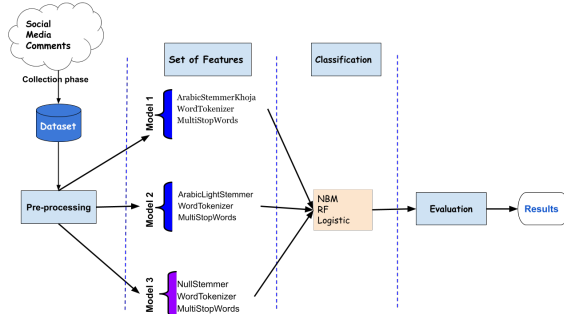


Fig. 2. Proposed architecture

### A. DataSet Description

Social media data is the main source of our Data set. We have built our own Data set which contains words and sentences in HASSANIYA by gathering hundreds of comments from Facebook pages using scrap tools that present cytosine's reaction to government activities and then annotating them according to their polarity. We annotated each comment extracted according to his opinion hidden behind the writing.

The corpus of the dataset is present in the below Table 2.

TABLE II. DATASET

| Class | Comment |
|---|---|
| Positive | 321 |
| Negative | 348 |
| Neutre | 337 |
| **Total** | 1006 |

Based on our knowledge of the local language, we divided the corpus into three categories looking at opinions reflected as positive, negative, and neutral as well as shown in Fig. 3. Moreover, we loaded comments on Interim storage as a CSV file after converting it to ARFF format for use on Weka.
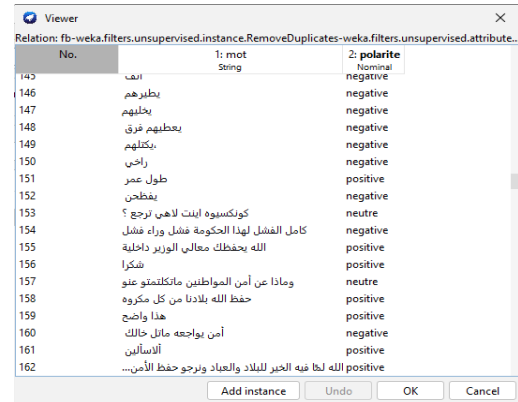


Fig. 3. DataSet example annotated.

The data was balanced by the Smote method as well as shown in the following Fig. 4.
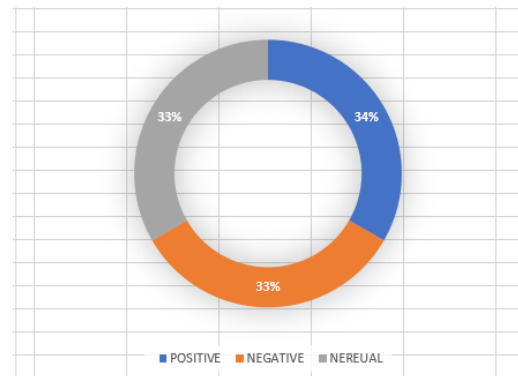


Fig. 4. DataSet balanced.

## B. Pre-processing

Pre-processing is the first step in the data analysis process and that is a crucial step when dealing with Arabic documents [17]. In order to convert input data to a performed text clearly and useful for machine analyses, we were using in this work a process consisting of various steps presented in the following. thus, these steps and filtering are offered by the Weka tool.

*Tokenization :* Tokenization is a technique that divides and transforms the word into tokens while preserving the meaning of the words by removing spaces, punctuation, and non-Arabic words [18]; in this case, the document is also reduced to words.

*Normalisation :* Word normalization means giving a format where some letters appear differently [19] for instance, ١, can appear in different forms like أ, آ and إ .

*StopWordsHandler :* stop word is used to eliminate everything not part of the word's root.

*Stemming :* The streaming method is an essential step in Natural Language Processing or text classification, which converts the word into its corresponding root or stem. stem is the combination of a root and its derivation which is a suffix prefix and postfix [16]. There are two main types of stemming in Arabic, namely Stem or Light Stemming and root-based stemming, the first one can be explained by removing the suffix and prefixes from the word in order to obtain its root; The second type is divided into three sub-categories. according to [17] such as (i) Dictionary Based when using a file dictionary; like khoja. (ii) no-dictionary bases, and hybrid that is shown in Fig. 5. There are several Stemming approaches applied to the Arabic language the following is a non-exhaustive type.

*Light stemmer :* Light stemmer is one category of stemming approach that aims to reduce words to their stem by means of removing the most frequent word's prefix and/or suffix [20], [21], [19] .

*Heavy Stemmer :* Heavy stemming is the process of eliminating affixes and changing certain letters in words to obtain the root word [22].
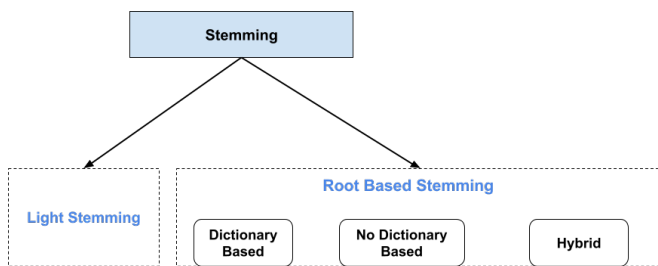


Fig. 5. Stemming structure approach.

*SetMinTermFreq() :* The SetMinTermFreq() method is used to define the minimum frequency threshold of a term (word) to be taken into account in the feature vector; In Weka, the StringToWordVector filter allows us to convert a collection of text documents into a set of numerical features, where each feature represents the frequency of a specific word in the document. In this study, you have used a minimum frequency equal to 2.

## C. WEKA tools

WEKA is a machine learning framework with a graphical user interface, making it easy to use for beginners. it also includes a large collection of machine learning models such as Neural Networks, Decision Trees, and K-means. provides implementations of learning algorithms that can be applied for data analysis purposes [23].

Weka covers tools for transforming datasets, such as discretization and sampling algorithms for pre-processing a dataset, integrating it into a learning scheme, and analyzing the resulting classifier and its performance.

## D. Machine Learning Algorithms

*1) Naive Bayes Multinominal :* Naïve Bayes (NB) is a data mining algorithm dedicated to data classification [24]. It is used to deduce the probability of a datum belonging to a class, based on the assumption that all attributes are independent of each other given the class [25]. In this work, we use Multinomial Naive Bayes to assign texts to classes based on statistical analysis of their content. This algorithm offers an alternative to the often cumbersome semantic analysis based on artificial intelligence and considerably simplifies the classification of textual data. It aims to classify by assigning text fragments to classes while determining the probability of a document belonging to the class in other documents with the same subject.

*2) Random Forest :* According to [26] RF is a set of decision trees where each tree is built from a bootstrap version of the training data set. Each tree is built according to the principle of repetitive partitioning: starting from the root node, the same node-splitting procedure is applied repeatedly until certain stopping rules are met. Its predictive power comes from the aggregation of many weaker learners (decision trees). Performance is particularly good if correlations between forest trees are low.

*3) Logistic :* Logistic regression is an important technique in the field of artificial intelligence and machine learning for data analysis that uses mathematics to find relationships between two data factors. It then uses this relationship to predict the value of one of these factors as a function of the other. The prediction usually has a finite number of outcomes, such as yes or no. Logistic regression belongs to the family of supervised machine learning models. It is also considered a discriminative model, meaning that it attempts to distinguish between classes (or categories) [27].

## E. Evaluation Metrics

Text classification models are evaluated using well-defined essential criteria. This set was used to evaluate our models [28]. To evaluate the accuracy of our Models', a confusion metric is defined by [10] as a tool to evaluate the accuracy of ML models' predictions and compare their predictions to reality. Since We have three classes to be classified, six important terms will have come into the evaluation process as shown

in Fig. 6. Results obtained are assessed using the F1 score, precision, accuracy, and recall.

*Tp:* here is true Positive, where the prediction is positive, and the actual values are positive also.

*Fp:* here is a False positive, where the prediction is positive, but the actual values are Negative or Neutral.

*Tng:* here is true Negative, where the prediction is negative, and the actual values are negative.

*Fng:* here is a false negative, where the prediction is negative, but the actual values are positive or neutral.

*Tn:* here is true Neutral, where the prediction is neutral, and the actual values are Neutral also.

*Fn:* here is a false Neutral, where the prediction is neutral, but the actual values are positive or negative also.

*Precision :* Precision (P) measures how many of the "positive" predictions are made correctly by the model. The mathematical formula is as follows :

$$P = \frac{\mathcal{T_P}}{\mathcal{T_P} + \mathcal{F_P} + \mathcal{F_P}} \tag{1}$$

*Recall :* Recall(R) measures how many of the positive class samples present in the dataset were correctly identified by the model. calculated by the following mathematical formula:

$$\mathcal{R} = \frac{\mathcal{TP}}{\mathcal{TP} + \mathcal{F_{Ne}} + \mathcal{F_N}} \tag{2}$$

*F-Measure :* F-Measure or F1 score is a machine-learning evaluation metric that measures a model's accuracy. It combines the precision and recall scores of a model. given by the formula:

$$\mathcal{F}1 = 2 * \frac{P * \mathcal{R}}{P + \mathcal{R}} \tag{3}$$

*Accuracy :* The accuracy metric computes how many times a model made a correct prediction across the entire dataset.

$$Accuracy = \frac{\mathcal{T_P} + \mathcal{T_N} + \mathcal{T_{Ng}}}{\mathcal{F_N} + \mathcal{T_N} + \mathcal{T_P} + \mathcal{F_P} + \mathcal{T_{Ng}} + \mathcal{F_{Ng}}} \tag{4}$$



Fig. 6. Confusion metrics for three classes.

## V. RESULTS AND DISCUSSION

There are three experimental works carried out using Weka tools are shown in Table III, in order to investigate the stemmer method effect in Mauritania dialectal classification and to compare the performance of the Machine Learning techniques applied. In the first EXP (i), we combined the ArabicStemmerkhoja, the MultiStopwords, and the word tokenizer in order to construct an appropriate feature; Exp (ii) is the result of a combination of ArabicLightStemmer, multistop-word, and word tokenizer; The last one EXP(iii) was done of null Stemmer combined with multi Stop Words, and WordTokenizer. The accuracy of the three experimental works is illustrated in Fig. 7 and Table VII, which shows that three machine learning techniques (Random Forest, Logistic Regression, and Naive Bays Multinomial) were tested using training data at three different stages, with the result changing according to features used.

TABLE III. COMBINED FEATURES

| Exp | Feature set |
|---|---|
| i | WordTokenize + ArbicStemmerKhoja + MultiStopWords |
| ii | WordTokenize + Arabic light Stemmer + MultiStopWords |
| iii | WordsTokenize + Null Stemmer + MultiStopWords |

Tables IV, V, and VI shows the results obtained by the Random Forest, NBM, and logistic techniques on the basis of the training data. It can be seen that the three classifiers managed to classify the positive class more than the others with better data by RF with Ligth StemmerArabic equal 98,5%; moreover, RF gets better results than others classified in three cases.

TABLE IV. EXP(I) CLASSIFICATION RESULTS OF EACH CLASS USING STEM-BASED (LIGTH STEMMERARABIC)

| | | Class | | |
|---|---|---|---|---|
| | | Positive | Negative | Neutral |
| NBM | Precision | 0,768 | 0,685 | 0,694 |
| | Recall | 0,731 | 0,726 | 0,686 |
| | F-Measure | 0,749 | 0,705 | 0,690 |
| RF | Precision | 0,985 | 0,974 | 0,934 |
| | Recall | 0,974 | 0,938 | 0,979 |
| | F-Measure | 0,980 | 0,956 | 0,956 |
| Logistic | Precision | 0,841 | 0,761 | 0,768 |
| | Recall | 0,840 | 0,776 | 0, 755 |
| | F-Measure | 0,841 | 0,768 | 0,762 |

The results obtained from exp(i) with Light Stemmer Arabic are shown in Table IV; this shows the performance evaluation measure for each selected class or sentiment (positive, negative, and neutral), so positive sentiment was ranked higher by RF.

Table V shows the results obtained when using Arabic Stemmer Khoja. This experience shows RF arrives at a significant number classified in all classes, followed by Logistic which is better for the positive, and negative classes than the neutral.

The results obtained during the exp(iii) indicated in Table VI show that RF and Logistic in terms of classification than NBM. However, the correctly classified number of the neutral class is less important here than the other classes.

TABLE V. EXP(II) CLASSIFICATION RESULTS OF EACH CLASS USING ROOT-BASED (ARABIC STEMMER KHOJA)

| | | Class | | |
|---|---|---|---|---|
| | | Positive | Negative | Neutral |
| NBM | Precision | 0,766 | 0,681 | 0,679 |
| | Recall | 0,705 | 0,749 | 0,665 |
| | F-Measure | 0,734 | 0,713 | 0,672 |
| RF | Precision | 0,982 | 0,951 | 0,952 |
| | Recall | 0,968 | 0,956 | 0,961 |
| | F-Measure | 0,975 | 0,953 | 0,956 |
| Logistic | Precision | 0,863 | 0,812 | 0,755 |
| | Recall | 0,796 | 0,951 | 0,801 |
| | F-Measure | 0,945 | 0,804 | 0,777 |

TABLE VI. EXP(III) CLASSIFICATION RESULTS OF EACH CLASS USING NULL STEMMER)

| | | Class | | |
|---|---|---|---|---|
| | | Positive | Negative | Neutral |
| NBM | Precision | 0,787 | 0,674 | 0,688 |
| | Recall | 0,705 | 0,746 | 0,686 |
| | F-Measure | 0,744 | 0,708 | 0,687 |
| RF | Precision | 0,985 | 0,945 | 0,946 |
| | Recall | 0,965 | 0,953 | 0,958 |
| | F-Measure | 0,975 | 0,949 | 0,952 |
| Logistic | Precision | 0,872 | 0,820 | 0,762 |
| | Recall | 0,853 | 0,796 | 0, 801 |
| | F-Measure | 0,862 | 0,808 | 0,781 |

Metric in the three experiments for the three classes given with the NMB and Logistic, it shows that the technique used is good for predicting the positive class, especially in experiment (i), and bad for predicting the negative class. Unlike RF who managed to predict all classes.
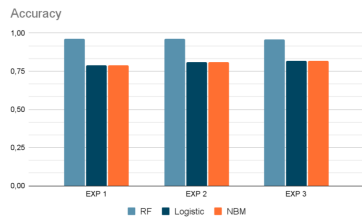


Fig. 7. Accuracy performance of the three algorithms.

Fig. 7 illustrates the Accuracy of algorithms given respectively by the three experiments applied.

TABLE VII. MODELS PERFORMANCE

| | Accuracy | | |
|---|---|---|---|
| EXP | RF | NBM | LOGISTIC |
| (i) | 96.37 | 71.40 | 79.02 |
| (ii) | 96.14 | 70.63 | 80.79 |
| (iii) | 95.84 | 71.24 | 81.65 |

As shown in Table VII above RF and NBM algorithm was better in performance when using ArbicStemmerKhoja; however, Logistic gets better performance results with Null Stemmer. Overall, with the Light Stemmer Arabic feature, the RF algorithm had the highest accuracy rate compared to the NBM and Logistic algorithms.

TABLE VIII. COMPARISON OF EXPERIMENTAL RESULTS

| Paper | Dataset | Classification Algorithm | Best Accuracy |
|---|---|---|---|
| [29] | Scrapping from tweets comments | SVM, NB, and K-nearest neighbour | 67.19% |
| [30] | Moroccan sentiment analysis corpus | NB, SVM , and Maximum Entropy (ME) | 82.5% |
| [31] | Tunisian sentiment analysis corpus | SVM, and NB | 76.41% |
| **Our approach** | **Mauritania dialect analysis corpus** | **NBM, RF , and Logistic Regression** | **96.37%** |

Table VIII illustrates the results obtained with previous work, which focuses on different dialects; Likewise, our approach also studies a dialect. However, the experimental study in this approach gave a result of 96.37% higher than those obtained by existing studies. Therefore it is a successful approach.

Diacritization and derivation or rootization of Arabic words are the limitations of this approach. We recommend that future research enhance algorithms by taking diacritization and all possible word lengths into account; So that the correct word meaning can be processed.

## VI. CONCLUSION

This study essentially focuses on the Mauritanian dialect, looking at its morphology, structure, and meaning, with the aim of analyzing it using Machine Learning algorithms. In order to prove the classification of the Mauritanian dialect using ML algorithms, we experimented on a corpus of dialect words that gave satisfactory results, however, the study proved that the results obtained are influenced by the effect of stemmer methods;

In this article, three types of stemmer were tested with the objective of measuring and comparing their effect on the classification of dialect text, this process showed that the stemmer method "ArbicStemmerKhoja" is the most efficient with the NBM and RF algorithms in terms of prediction, unlike logistic which gives a better performance without stemmer.

These results will guide us to a deeper study of the language data in order to uncover sentiments behind his comments written in the Mauritanian dialect and find an accurate prediction.

## ACKNOWLEDGMENT

## REFERENCES

[1] P. P. Rokade and K. D. Aruna, "Business intelligence analytics using sentiment analysis-a survey," *International Journal of Electrical and Computer Engineering*, vol. 9, no. 1, p. 613, 2019.

[2] M. E. M. El Arby Chrif, M. M. Saleck, A. C. M. N'Diaye, and E. B. M. Mahmoud, "Business intelligence models for e-government in mauritania: A survey," in *The International Conference on Artificial Intelligence and Smart Environment.* Springer, 2022, pp. 307–312.

[3] A. C. M. N'Diaye, M. E. M. E. A. Chrif, B. M. El Mahmoud, and O. El Beqqali, "Apply sentiment analysis technology in social media as a tool to enhance the effectiveness of e-government: Application on arabic and mauritanian dialect 'hassaniya'," in *2021 Fifth International Conference On Intelligent Computing in Data Sciences (ICDS).* IEEE, 2021, pp. 1–5.

[4] A. Y. Muaad, G. H. Kumar, J. Hanumanthappa, J. B. Benifa, M. N. Mourya, C. Chola, M. Pramodha, and R. Bhairava, "An effective approach for arabic document classification using machine learning," *Global Transitions Proceedings*, vol. 3, no. 1, pp. 267–271, 2022.

[5] P. F. Kurnia *et al.*, "Business intelligence model to analyze social media information," *Procedia Computer Science*, vol. 135, pp. 5–14, 2018.

[6] A. Alshutayri, E. Atwell, A. Alosaimy, J. Dickins, M. Ingleby, and J. Watson, "Arabic language weka-based dialect classifier for arabic automatic speech recognition transcripts," in *Proceedings of the Third Workshop on NLP for Similar Languages, Varieties and Dialects (VarDial3)*, 2016, pp. 204–211.

[7] S. U. Hassan, J. Ahamed, and K. Ahmad, "Analytics of machine learning-based algorithms for text classification," *Sustainable Operations and Computers*, vol. 3, pp. 238–248, 2022.

[8] H. Alshaer, B. Alzwahrah, and M. Otair, "Arabic text classification using bayes classifiers," *Int J Inform Syst Comput Sci*, 2017.

[9] M. A. Sghaier, H. Abdellaoui, R. Ayadi, and M. Zrigui, "Analyse de sentiments et extraction des opinions pour les sites e-commerce: application sur la langue arabe," in *5th International Conference on Arabic Language Processing (CITALA)*, 2014.

[10] M. Errami, M. A. Ouassil, R. Rachidi, B. Cherradi, S. Hamida, and A. Raihani, "Sentiment analysis on moroccan dialect based on ml and social media content detection," *International Journal of Advanced Computer Science and Applications*, vol. 14, no. 3, 2023.

[11] N. J. Thalji, E. Aljarrah, R. Rateb, and A. R. M. Al-Shorman, "New arabic root extraction algorithm," *International Journal of Advanced Computer Science and Applications*, vol. 14, no. 5, 2023.

[12] M. A. Humayun, H. Yassin, and P. E. Abas, "Dialect classification using acoustic and linguistic features in arabic speech," *IAES International Journal of Artificial Intelligence*, vol. 12, no. 2, p. 739, 2023.

[13] T. Kanan, B. Hawashin, S. Alzubi, E. Almaita, A. Alkhatib, K. A. Maria, and M. Elbes, "Improving arabic text classification using p-stemmer," *Recent Advances in Computer Science and Communications (Formerly: Recent Patents on Computer Science)*, vol. 15, no. 3, pp. 404–411, 2022.

[14] M. O. Hegazi, Y. Al-Dossari, A. Al-Yahy, A. Al-Sumari, and A. Hilal, "Preprocessing arabic text on social media," *Heliyon*, vol. 7, no. 2, 2021.

[15] J. Younes, E. Souissi, H. Achour, and A. Ferchichi, "Un état de l'art du traitement automatique du dialecte tunisien [natural language processing of the tunisian dialect: a state of the art]," *Traitement Automatique des Langues*, vol. 59, no. 3, pp. 93–117, 2018.

[16] B. Abuata and A. Al-Omari, "A rule-based stemmer for arabic gulf dialect," *Journal of King Saud University-Computer and Information Sciences*, vol. 27, no. 2, pp. 104–112, 2015.

[17] H. A. Almuzaini and A. M. Azmi, "Impact of stemming and word embedding on deep learning-based arabic text categorization," *IEEE Access*, vol. 8, pp. 127 913–127 928, 2020.

[18] T. SSIT and B. BIT, "Document classification system using improvised random forest classifier."

[19] H. Elfaik *et al.*, "Leveraging feature-level fusion representations and attentional bidirectional rnn-cnn deep models for arabic affect analysis on twitter," *Journal of King Saud University-Computer and Information Sciences*, vol. 35, no. 1, pp. 462–482, 2023.

[20] T. Kanan, O. Sadaqa, A. Almhirat, and E. Kanan, "Arabic light stemming: A comparative study between p-stemmer, khoja stemmer, and light10 stemmer," in *2019 Sixth International Conference on Social Networks Analysis, Management and Security (SNAMS).* IEEE, 2019, pp. 511–515.

[21] H. Al Ameed, S. Al Ketbi, A. Al Kaabi, K. Al Shebli, N. Al Shamsi, N. Al Nuaimi, and S. Al Muhairi, "Arabic light stemmer: A new enhanced approach," in *The Second International Conference on Innovations in Information Technology (IIT'05)*, 2005, pp. 1–9.

[22] M. G. Syarief, O. T. Kurahman, A. F. Huda, and W. Darmalaksana, "Improving arabic stemmer: Isri stemmer," in *2019 IEEE 5th International Conference on Wireless and Telematics (ICWT).* IEEE, 2019, pp. 1–4.

[23] S. Lang, F. Bravo-Marquez, C. Beckham, M. Hall, and E. Frank, "Wekadeeplearning4j: A deep learning package for weka based on deeplearning4j," *Knowledge-Based Systems*, vol. 178, pp. 48–50, 2019.

[24] L. Zhang, L. Jiang, C. Li, and G. Kong, "Two feature weighting approaches for naive bayes text classifiers," *Knowledge-Based Systems*, vol. 100, pp. 137–144, 2016.

[25] P. Langley and S. Sage, "Induction of selective bayesian classifiers," in *Uncertainty Proceedings 1994.* Elsevier, 1994, pp. 399–406.

[26] J. Hu and S. Szymczak, "A review on longitudinal data analysis with random forest," *Briefings in Bioinformatics*, vol. 24, no. 2, p. bbad002, 2023.

[27] C. M. Richard, D. Poddubnyy, A. Deodhar, W. Bao, C. Parman, B. Porter, and E. Pournara, "Facteurs prédictifs de réponse au sécukinumab chez les patients atteints de spondylarthrite ankylosante: analyse par régression logistique et machine learning," *Revue du Rhumatisme*, vol. 87, p. A28, 2020.

[28] F. S. Alharithi, "Performance analysis of machine learning approaches in automatic classification of arabic language," 2023.

[29] R. M. Duwairi and I. Qarqaz, "Arabic sentiment analysis using supervised classification," in *2014 International Conference on Future Internet of Things and Cloud.* IEEE, 2014, pp. 579–583.

[30] A. Oussous, A. A. Lahcen, and S. Belfkih, "Improving sentiment analysis of moroccan tweets using ensemble learning," in *Big Data, Cloud and Applications: Third International Conference, BDCA 2018, Kenitra, Morocco, April 4–5, 2018, Revised Selected Papers 3.* Springer, 2018, pp. 91–104.

[31] S. Mdhaffar, F. Bougares, Y. Esteve, and L. Hadrich-Belguith, "Sentiment analysis of tunisian dialects: Linguistic ressources and experiments," in *Third Arabic Natural Language Processing Workshop (WANLP)*, 2017, pp. 55–61.

# Quantum Steganography: Hiding Secret Messages in Images using Quantum Circuits and SIFT

Hassan Jameel Azooz[*1], Khawla Ben Salah[2], Monji Kherallah[3], Mohamed Saber Naceur[4]

University of Almuthanna, Iraq[1]

University of Gafsa, Tunisia[2]

University of Sfax, Tunisia[3]

University of Carthage, Tunisia[4]

*Abstract*—In today's era of escalating digital threats and the growing need for safeguarding sensitive information, this research strives to advance the field of information concealment by introducing a pioneering steganography methodology. Our approach goes beyond the conventional boundaries of image security by seamlessly integrating classical image processing techniques with the cutting-edge realm of quantum encoding. The foundation of our technique lies in the meticulous identification of distinctive features within the cover image, a crucial step achieved through the utilization of SIFT (Scale-Invariant Feature Transform). These identified key points are further organized into coherent clusters employing the K-means clustering algorithm, forming a structured basis for our covert communication process. The core innovation of this research resides in the transformation of the concealed message into a NEQR (Novel Enhanced Quantum Representation) code, a quantum encoding framework that leverages the power of quantum circuits. This transformative step ensures not only the secrecy but also the integrity of the hidden information, making it highly resistant to even the most sophisticated decryption attempts. The strategic placement of the quantum circuit representing the concealed message at the centroids of the clusters generated by the K-means algorithm conceals it within the cover image seamlessly. This fusion of classical image processing and quantum encoding results in an unprecedented level of security for the embedded information, rendering it virtually impervious to unauthorized access. Empirical findings from extensive experimentation affirm the robustness and efficacy of our proposed strategy.

*Keywords*—*Clustering; keypoints; k-means; cover image; quantum steganography*

## I. INTRODUCTION

Digital document transfer via networks is vulnerable to a number of security threats, including attacker interception and modification. Different methods have been developed to safeguard the transfer of digital documents in order to reduce risk. Steganography is one such method, which entails concealing a message within another message or a tangible item. Researchers have recently put forth a number of steganography methods that mix classical and quantum computing methods. For instance, the hybrid quantum k-means algorithms described by Poggiali et al. [9] and DiAdamo et al. [8] combine classical and quantum clustering methods. Jiang and Wang [10] suggested a unique, safe, keyless steganography method based on the Moiré pattern for pictures on quantum computers. Li and Lu [7] introduced a brand-new LSB-based steganography for colored quantum pictures that makes use of reflected Gray coding. Even while these methods have showed potential, steganography still has limitations.

For instance, The secret message may be discovered if the steganography algorithm is known or if the cover item is subjected to statistical analysis [21]. This paper introduces a unique method of picture steganography that combines traditional image processing methods with quantum computing in order to overcome these constraints. The proposed method leverages Scale-Invariant Feature Transform (SIFT) for keypoint detection and K-means clustering [6]for image processing before encoding the secret message using quantum circuits. The secret message is then encoded into a Novel-Enhanced Quantum Representation (NEQR) code, providing an additional security layer. The suggested method is used to conceal a hidden message in a handwritten manuscript and document image. The main contribution of this approach lies in its innovative combination of classical image processing techniques with quantum computing to enhance the security and imperceptibility of steganography. Specifically, K-mean clustering introduces It provides an efficient way to group similar keypoints detected by SIFT and group them to find the optimal number of centroids of keypoints in the cover image. This ensures that the secret message is encrypted in a secure and efficient way. Followed by encoding the secret message using quantum circuits and NEQR coding. This not only enhances the security of the hidden message but also maintains the aesthetic quality of the original image. To overcome the limitations of steganography techniques, k-means unsupervised learning algorithm can be used to hide large data sets. It assumes that the detector parameters and K-means are completely synchronized between sender and receiver and that the quantum circuit used for encryption can be transmitted securely. The remainder of this paper is divided into the following sections. For background, in Section II, we review prior initiatives in the field of imagine steganography. We fully describe the methods we want to utilize in Section III. Experimental results demonstrating our approach's effectiveness are described in Section IV. Section V concludes the essay and discusses what happens next.

## II. RELATED WORKS

An area of study that is expanding quickly and has gotten a lot of attention lately is quantum image processing and information concealing. In order to improve the embedding capability, visual quality, and security of quantum image steganography, researchers have proposed forth several novel techniques for hiding information within quantum images. These techniques include Fourier's Quantum Information Processing [1], Image processing in quantum computers [2], turtle

shell algorithm [3], and least significant bit (LSB) replacement [4]. The publication "A novel quantum color image steganography algorithm based on the turtle shell and LSB" [3] describes one noteworthy technique. In order to increase visual quality and security, the authors provide a novel quantum color picture steganography technique that makes use of the human vision system (HVS) model and validates codes. To conceal secret information, the algorithm randomly chooses two channels from each color carrier pixel's red (R), green (G), and blue (B) channels with varying probability. The grayscale values of the two selected channels line up with a spot in the reference matrix based on a turtle shell. Either the LSB substitution technique or the turtle shell algorithm is used to embed the secret information, depending on whether the point is near the border of the reference matrix or not. The technique of the authors' unique system is better explained through the use of specialized quantum circuits. According to experimental findings, their algorithm is workable and performs better than competing techniques in terms of security, embedding ability, and imperceptibility. The article "LSB-based Steganography Using Reflected Gray Code for Color Quantum Images" [7] presents another intriguing technique. In order to increase embedding capacity and security for color quantum pictures, this research suggests an LSB-based steganography approach employing reflected Gray code. The authors include four hidden qubits into each pixel of the cover picture using the NEQR encoding for quantum images. In order to lessen distortion in the stego picture and make detection more challenging, they additionally use reflected Gray coding. Mario Mastriani's works and others are connected. The author in [1], who first up the idea of quantum Fourier transformation and investigated how it affected entanglement, teleportation, and quantum secret sharing. The author in [2] investigates how Quantum Image Processing (QIP) may be used to more effectively represent pictures by storing N bits of classical information in just log2 N quantum bits (qubits) and by using a brand-new LSB-based quantum image steganography algorithm. The many facets of quantum image processing and clustering approaches have also been examined in certain related publications. For instance, [8] provided a useful quantum k-means clustering method and examined its effectiveness and potential uses for classifying energy grids. This research showed how useful quantum clustering methods may be in real-world applications. In contrast to prior studies, our technique first processes the image before encoding the secret message using SIFT (Scale-Invariant Feature Transform) and K-means clustering. K-means is a clustering technique used to divide data into groups, whereas SIFT is an algorithm that finds and characterizes local features in photographs. You use quantum circuits to encrypt a secret message after utilizing SIFT to identify keypoints in a cover picture and K-means clustering to organize them into clusters. The result is a NEQR code. By changing the pixel values of the cover image, you may finally encrypt the secret message in the picture. The main difference between our approach and these related works is that our methodology concentrates on processing the image using SIFT and K-means clustering before encoding the secret message, whereas these works concentrate on improving the embedding capacity, visual quality, and security of LSB-based quantum image steganography or improving the efficiency of k-means clustering through quantum parallelism. Furthermore, unlike previous comparable research, our suggested approach includes machine learning techniques. With regard to your information concealment technique, we specifically use machine learning methods or models like K-means clustering for keypoint grouping or other pertinent activities. In comparison to conventional steganography approaches, our proposed work offers improved performance and flexibility by using machine learning techniques. The efficiency and efficacy of the information-hiding process are increased thanks to machine learning models' ability to recognize patterns, improve settings, and adjust to changing circumstances. In spite of these developments, there are still several issues and research gaps in this area. For instance, utilizing security metrics like entropy, correlation coefficient, chi-square test, etc. A more thorough security study and comparison with other quantum picture steganography systems already in use are required. Researchers must also take into account how assaults or quantum noise may impair the resilience and dependability of these solutions. Additionally, it is necessary to provide clearer descriptions of how models like HVS are used to choose channels for information concealment as well as their adaptability to various picture kinds and color schemes. To prove practicality and applicability, further experimental findings on real-world pictures or applications are required.

## III. Proposed Approach

### A. Image Pre-processing

Noise reduction, contrast enhancement, and edge detection techniques will be used on cover images to enhance their steganography. Edge detection will identify the edges of the image, contrast enhancement will change its brightness and blackness, and noise reduction will eliminate any extraneous pixels or imperfections. the things in the picture. The cover picture is then loaded and made grayscale. The keypoints detection technique only functions on grayscale pictures, hence the conversion to grayscale is required.

### B. Detection of Key Points

The Scale-Invariant Feature Transform (SIFT) technique will next be used to find relevant regions in the cover picture [24]. Here These strategic places will offer suitable hiding spots for the hidden message. In order to identify, describe, and match local characteristics in pictures, David Lowe created the SIFT algorithm in 1999 [5]. SIFT identifies and characterizes local features in images. It is a reliable option for key point identification since it is invariant to scale, orientation, and affine distortion. SIFT is used by our suggested technique to find key points in the cover picture. Key points are interesting areas of a picture that remain constant despite changes in scale and direction. The scale space of the input image is initially built as part of the SIFT algorithm's operation. This is accomplished by creating a collection of smoothed pictures by convolving the image with Gaussian filters at various scales. Next, neighboring smoothed pictures in the scale space are subtracted to determine the Difference of Gaussians (DoG). The local extrema (maxima and minima) are looked for across scales and spatial dimensions in the DoG pictures. These extremes might serve as important points. After possible key points have been discovered, they are refined by removing edge responses and low-contrast key points. The prevailing gradient direction in each key point's immediate vicinity is

then used to determine its orientation. The local image patch of each key point is used to construct a description for each of them. Equation [1] shows how the scale space is built using a Gaussian function:

$$G(x, y, \sigma) = \frac{1}{2\pi\sigma^2} e^{-\frac{x^2+y^2}{2\sigma^2}} \qquad (1)$$

where:

- $x$ and $y$ are the pixel coordinates.

- $\sigma$ is the scale parameter.

### C. Clustering of Key Points

In the suggested method, we employed the K-means clustering technique to organize the key points that were identified in the cover picture into clusters [19], [22]. This process is used to locate areas in the image where the hidden message could be hidden. The last places to implant the hidden message will be in the centroids of these clusters (10 centroids were employed can seen in Fig. 1). Unsupervised machine learning technique known as K-means divides a set of data points into K clusters [23]. Stuart Lloyd made the initial suggestion in 1957, and James MacQueen subsequently published it in 1967 [20]. The method updates the cluster centers based on the mean of the data points given to each cluster after repeatedly allocating each data point to the closest cluster center. When the cluster assignments stop changing, the algorithm has reached its convergence. Let $C = \{c_1, c_2, \ldots, c_k\}$ be the set of cluster centers and $\{X = x_1, x_2, \ldots, x_n\}$ be the collection of data points in mathematics. The within-cluster sum of squares (WCSS) [11], which is determined by Eq. (2), is the objective of K-means:

$$\sum_{i=1}^{k} \sum_{x \in C_i} \|x - c_i\|^2, \qquad (2)$$

where:

- $C_i$: the set of data points assigned to cluster $i$.

- $i$, and $\|x - c_i\|$: the Euclidean distance between data point $x$ and cluster center $c_i$.

The key points from the cover picture that were recognized by our suggested method were grouped into clusters using K-means clustering. The K-means method seeks to identify a clustering of the key points such that the key points within each cluster are as near as feasible to one another (in terms of their Euclidean distance) by minimizing the WCSS. As a consequence, a collection of neatly spaced-out key point clusters is produced. These clusters may then be utilized to find possible locations for the hidden message to be embedded. For instance, we may decide to place the hidden message in the pixels that correspond to the cluster centers or those that are a specific distance away from the cluster centers. We can make sure that the embedding spots are selected in a way that will probably retain the aesthetic quality of the cover picture by using K-means clustering to divide the key points into clusters.
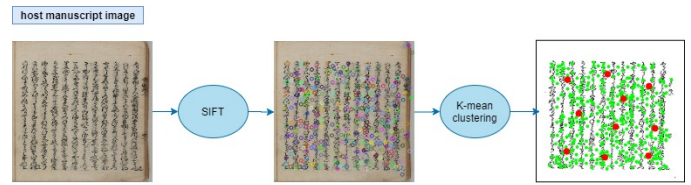


Fig. 1. Identification of the embedding positions.

### D. Encoding of Messages

In our suggested method, we harness the power of quantum circuits and keypoint clustering to safely insert a hidden message into a picture. We can find the best places to integrate messages while still maintaining the aesthetic appeal of the cover picture by utilizing keypoint clustering. The K-means technique was used to create these clusters, which may be used to find possible locations for the secret message to be embedded. For instance, we may decide to place the hidden message in the pixels that correspond to the cluster centers or those that are a specific distance away from the cluster centers. We begin by employing SIFT and K-means clustering to find and group the key points, then we use quantum circuits to encrypt the secret message and produce a Novel-Enhanced Quantum Representation (NEQR) coding for the message. This technique is an illustration of the Proposed KeyPoints Clustering and Quantum Circuits technique. First, translate the hidden message into binary form. To do this, transform each character in the secret message to its corresponding ASCII code before converting it to an 8-bit binary string. Let's propose that we have a binary secret message (B message) and a quantum circuit $Q$ with $n = 144$ qubits initialized to the $|0\rangle$ state.

A tensor combination of the several qubit states may be used to describe the starting state of the quantum circuit in Eq. (3):

$$|\psi\rangle = |0\rangle \otimes |0\rangle \otimes \ldots \otimes |0\rangle, \qquad (3)$$
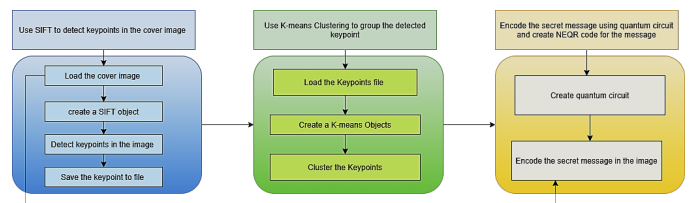


Fig. 2. Overview of the process of encoding messages.

The size of the binary secret message divided by $n$ will determine the number of qubits in the quantum circuit that will be created subsequently. This flips the state of that qubit from $|0\rangle$ to $|1\rangle$. The binary secret message is first encoded into the quantum circuit, and then it is changed into a gate to produce the NEQR code for the secret message. This would produce a gate called neqr_code that would reflect the secret message's NEQR code. Then, using the appropriate files, we load this NEQR code into the cover picture and cluster centers. The cover graphic then contains red markers for the cluster centers. Then, according to each pixel value's binary representation,

the binary secret message is concealed in the least significant bit (LSB). This is accomplished by iteratively going through each pixel and changing the value of the blue channel to encode one bit of the binary secret message. A file is then created with the finished stego image. Instead of adding a new signal on top of the cover data, this method provides an extra degree of protection by enclosing the secret message inside the image itself. It is harder for an enemy to discover the hidden message when it is concealed inside the image itself. Furthermore, Fig. 2 illustrates how even if an enemy were to discover its existence, they would still need to understand how it was encoded in order to decode it and obtain the information. Because it is challenging to identify the secret message in the cover image, the system is safe. Each ASCII character's LSB only differs by one bit, making it incredibly challenging to identify. The plan also employs a random scrambling process to further muddle the secret message. The approach is especially effective because it doesn't necessitate sending a lot of extra data. The secret message's ASCII representation is the only extra information that is necessary. NEQR (new enhanced quantum representation), a novel enhanced quantum representation for digital pictures, was put out as an enhancement to the Flexible Representation of Quantum pictures (FRQI) paradigm [12]. Instead of using a qubit's probability amplitude, as in FRQI, the NEQR model stores the basic state of a qubit sequence as the initial gray-scale value for each pixel in an image. The NEQR quantum image can differentiate between several gray scales because the basic states of a qubit sequence are orthogonal [12]. A quadratic speedup in quantum picture preparation, a 1.5X improvement in quantum image compression, and reliable digital image retrieval from quantum images are all demonstrated by NEQR in performance comparisons with FRQI. NEQR also makes it easier to conduct other quantum image operations linked to the picture's grayscale data, such as partial and statistical color operations. As a result, compared to existing models in the literature, the proposed NEQR quantum image model is more adaptable and more suitable for quantum picture representation. The NEQR (new enhanced quantum representation) coding and LSB (least significant bit) replacement are utilized in the proposed method to add another level of security to the encoded communication. While the cover picture's cluster centers are colored red using NEQR coding, the secret message's binary representation is encoded into the pixel values of the stego image using LSB substitution. This provides a way to indicate specific locations where the secret message can be found in the cover image. There are various advantages of using NEQR coding in this project. For instance, it could be harder for an attacker to figure out whether the image contains a secret message. In order to effectively decode the secret message, an attacker has to be familiar with both LSB substitution and NEQR coding. NEQR coding can also give a mechanism to check the message's integrity after it has been encoded. The NEQR code identifies precise spots in the cover picture where the hidden message may be identified (extraction algorithm), and by comparing these marked sites to the original cluster centers, it is possible to identify any alterations made to these locations (for example, as a result of image compression or editing).

---

**Algorithm 1** Clustering of Proposed KeyPoints and Quantum Circuits

---

**Require:** Cover Image (CI), Secret Message (SM)
1: CI: Cover Image
2: SI: Stego Image
3: SM: Secret Message
4: BSM: Binary Secret Message
5: NEQR: Novel-Enhanced Quantum Representation
6: **Output:** Stego Image, Decoded Message
7: **Step 1: Detect Keypoints in the CI**
8: Load the CI using OpenCV library.
9: Create a SIFT object.
10: Detect keypoints in the CI using SIFT.
11: Save the keypoints information to a file.
12: **Step 2: Cluster the Detected Keypoints**
13: Load the keypoints file.
14: Convert the keypoints information.
15: Create a K-means object with desired clusters.
16: Perform K-means clustering.
17: Save cluster centers to a file.
18: **Step 3: Encode the Secret Message using Quantum Circuits**
19: Convert the SM into binary.
20: Create a quantum circuit with qubits equal to BSM length.
21: **for** each qubit **do**
22:    Check bit value of BSM.
23:    **if** bit is '1' **then**
24:       Apply an X gate.
25:    **end if**
26: **end for**
27: Convert the circuit to a NEQR gate.
28: **Step 4: Encode the Secret Message in the CI**
29: Load the CI again.
30: Load cluster centers.
31: Mark centers in the CI with red color.
32: Create SI copy.
33: Get SI dimensions.
34: Initialize binary index to 0.
35: **for** each pixel in SI **do**
36:    Get pixel value.
37:    **if** binary index $<$ BSM length **then**
38:       Calculate new pixel value.
39:       Set blue channel to original value minus LSB plus BSM bit.
40:       Update SI pixel.
41:       Increment binary index.
42:    **end if**
43: **end for**
44: Save SI to a file.

---

*E. Secret Message Extraction and Decoding*

The original secret message is obtained by extracting the NEQR code from the stego picture. In order to decode the NEQR code, one must first measure the quantum circuit, then take the least significant bit from each pixel value in the stego picture and combine it with other bits to create a binary string. To extract the original secret message, this binary string may then be transformed into a character string. This is how Eq.

TABLE I. STRUCTURAL SIMILARITY INDEX METRICS (SSIM)

| Benchmarks | PSNR |
|---|---|
| Lena | 54.2827 |
| Baboon | 50.6742 |
| Cameraman | 51.410 |
| Toobacoo800 | 54.6244 |
| MNIST | 51.142 |
| IAM dataset | 47.016 |
| CASIA Handwriting dataset | 47.464 |
| EMNIST | 51.1661 |
| Signature dataset | 46.0929 |
| Dataset-1 | 46.555 |

(4) should be written:

$$b = p \mod 2, \tag{4}$$

## IV. EXPERIMENTAL RESULTS

This section presents the outcomes of evaluations conducted on the proposed steganography system. The system was assessed regarding imperceptibility and robustness using widely accepted techniques such as Peak signal-to-noise ratio (PSNR), SSIM, BER techniques, and histogram analysis.

### A. Context and Parameters

The proposed algorithm included several vital parameters, such as the number of octaves and the number of scale levels within each octave in the scale. In k-mean, the primary parameter is the number of clusters(K) that have been determined and then applied to the set of squares within the double WCSS set for a range of K values. The quantum circuit parameters are the number of qubits determined by the length and state of the binary secret message.

### B. Datasets

In the conducted experiments, a selection of renowned handwriting datasets was employed. These encompass the EMNIST dataset [13], the MNIST database, the IAM handwriting database [14], CASIA Handwriting Database [15], and the Chars74k dataset. These particular datasets furnish an extensive assortment of handwritten characters and digits, thereby serving as a robust testing ground for the algorithm under scrutiny.

### C. Imperceptibility

We evaluated the imperceptibility of our steganography system using three metrics: PSNR, SSIM, and histogram analysis. Image quality is quantified by the Peak Signal-to-Noise Ratio (PSNR) [16]. The ratio of the signal's highest achievable power to the noise's power affects the accuracy of the representation [16]. The following Eq. (5). can be used to determine the PSNR, which is typically reported in dB

$$PSNR = 10 \cdot \log_{10}\left(\frac{MAX^2}{MSE}\right), \tag{5}$$

Where MAX is the maximum possible pixel value of the image (e.g. 255 for 8-bit images) and MSE is the mean squared error between the cover image and the stego image. We calculated the PSNR values for several datasets using this equation (Table I).

The Structural Similarity Index Metrics (SSIM), measures the structural similarity between two images. It is designed to capture the perceived change in structural information between two images. The formula for determining the SSIM is as follows [17](6):

$$SSIM(x,y) = \frac{(2\mu_x\mu_y + c_1)(2\sigma_{xy} + c_2)}{(\mu_x^2 + \mu_y^2 + c_1)(\sigma_x^2 + \sigma_y^2 + c_2)}$$

c represents the cover image, and s represents the stego image. $\mu_c$ and $\mu_s$ are the average pixel values of images $c$ and $s$, respectively. These values are used to compare the luminance of the two images. $\sigma_c^2$ and $\sigma_s^2$ are the variances of images $c$ and $s$, respectively. These values are used to compare the contrast of the two images. $\sigma_{cs}$ is the covariance of images $c$ and $s$. This value is used to compare the structure of the two images. We calculated the SSIM values for several datasets using this equation. And since the resulting number of SSIM ranges from -1 to 1, with one indicating that the cover and stego images are identical. A higher SSIM value that achieved (0.99) indicates that the structural similarity between the cover and stego images is high.

### D. Histogram Analysis

It was performed to evaluate the distribution of pixel intensities in the stego images compared to the original cover images. The results displayed in Fig. 3 confirms that the histograms of the cover and the image of Stego were very similar since our steganography system does not introduce significant changes to the histograms of the images. To determine the differences between cover images and stego, we performed a histogram analysis of the pixel difference (PDH) between document images, handwritten manuscripts four benchmarks: man from Standard test images(c1), Tobacoo800(c2), L3iDocCopies(c3) and EMNIST(c4) and the resulting stego images-histogram, respectively (s1, s2,s3,s4) man, Tobacoo800, L3iDocCopies and EMNIST (Table II). The difference values between the cover images and the resulting stego were minimal, which confirms the superiority of our proposed approach in achieving the minimum level of distortion during the data embedding. The images show that our proposed system has a minimal visual impact on the paper, which preserves readability while making it difficult to determine the exact locations of the embedded message. Fig. 4 presents document images and stego manuscripts resulting from the use of the proposed system in including the secret message for three types of dataset used, where it can be seen that the documents remain clear because our system did not affect the image of the document in a way that prevents discovering the location of the secret message being included in it. In addition, the evaluation of our proposed system includes a comparison between SSIM and PISNR in Fig. 5. These results were obtained using ten images from the data set used in evaluating the system, including images of handwritten documents and manuscripts, which show that 54.62 and 0.99 are the average values of PSNR and SSIM of our proposed system, respectively. The maximum values of both PSNR and SSIM are 1, and thus our approach produces high quality images of Stego documents. Fig. 6 presents a comparison of the PSNR of our proposed system with related works, including standard least significant bits (LSB) [3], [Li, Panchi, and Aiping Lu] [7], and [Zhou, Ri-Gui, et al.] [4].

Through this comparison, it can be seen that the method of [3] is superior to other related researches, except for the technique used in Our proposed approach. This confirms the validity of high image quality, which reduces the chances of detecting the Human Visual System (HVS).

TABLE II. COVER-STEGO-DOCUMENT PIXEL DIFFERENCE HISTOGRAM ANALYSIS

| Benchmark | Cover image | Stego image | (PDH) analysis |
|---|---|---|---|
| Standard test images (Man) | C1 | S1 | 0.18 |
| Tobacco800 | C2 | S2 | 0.21 |
| L3iDocCopies | C3 | S3 | 0.22 |
| EMNIST | C4 | S4 | 0.29 |
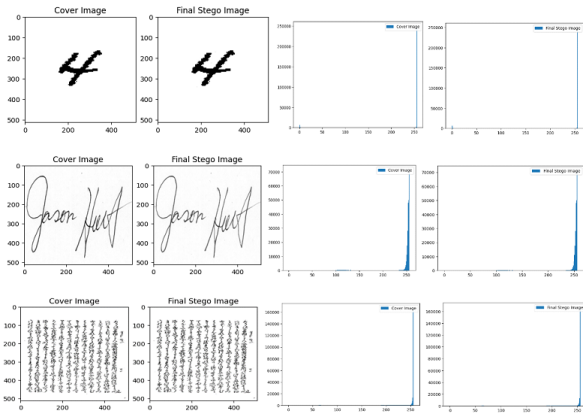


Fig. 3. Histograms of similarity the cover and stego images.

### E. Robustness Evaluation

Due to possible rotational distortion brought on by printing and scanning disturbances, the original form of the encoded document must be restored before hidden message detection. That the accuracy ratio of extracted message bits is evaluated using the Bit Error Ratio (BER), which is also used further to evaluate the robustness of the extracted secret message. The Bit Error Rate (BER) measures how accurately a secret message can be extracted from a stego image. It is the ratio between the number of incorrect bits in the extracted message and the total number of bits in the original message [18]. A lower BER value indicates a better resistance to errors or alterations in the stego image as referred in Table III.

TABLE III. BIT ERROR RATE (BER) FOR DIFFERENT BENCHMARKS

| Benchmarks | BER |
|---|---|
| Lena | 0.0037 |
| Baboon | 0.00601 |
| Cameraman | 0.0031 |
| Tobacco800 | 0.00234 |
| MNIST | 0.0027 |
| IAM dataset | 0.0073 |
| CASIA Handwriting dataset | 0.00741 |
| EMNIST | 0.0041 |
| Signature dataset | 0.0087 |
| Dataset-1 | 0.0076 |

The table demonstrates that our steganography system consistently produced low BER values across multiple datasets, showing that the bit error rate is minimal and the secret
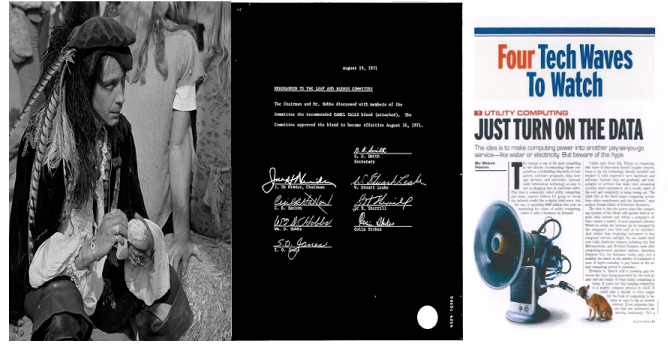


Fig. 4. Stego documents samples

message can be accurately recovered from the stego pictures. In conclusion, the testing findings from our steganography technology demonstrate its high levels of stealth and durability. The method can conceal information in high-quality and structurally comparable images with a low bit error rate.
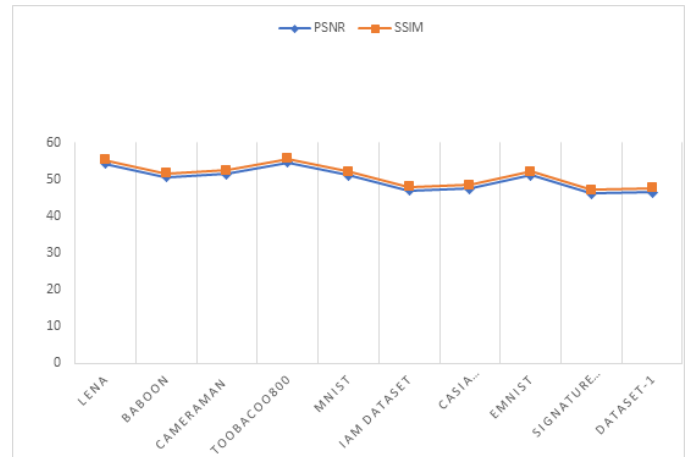


Fig. 5. PSNR and SSIM of ten stego document image quality.

### F. Comparison with Related Works

To evaluate the performance of our steganography method compared to the related works, we conducted experiments using specific datasets and measured the PSNR values. The results are summarized in the Table IV:

TABLE IV. COMPARISON AMONG VARIOUS WORKS AND OUR PROPOSED WORK

| Dataset | Our Proposed Work | Wang et al. (3) | Li et al. (7) | Zhou et al. (4) |
|---|---|---|---|---|
| Lena | 54.2827 | 54.59 | 50.58 | 50.21 |
| Baboon | 50.674221 | 54.59 | - | - |
| Cameraman | 51.410 | - | - | 50.19 |

As can be seen from the table, our steganography system achieved competitive PSNR values compared to existing methods on several datasets. These results indicate that our system can hide secret messages in images with high image quality. In summary, our experimental results show that our

steganography system achieves high imperceptibility in terms of PSNR. The system can hide secret messages in images with high image quality as measured by this metric.
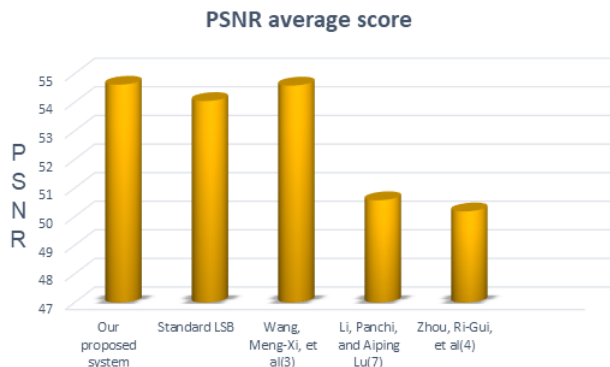


Fig. 6. A comparison of the proposed approach based on peak signal to noise ratio PSNR with state of the art methods.

## V. Conclusion

In this paper, we presented a novel steganography system that combines quantum circuits and classical image processing techniques to hide secret messages in images. Our system uses the Scale-Invariant Feature Transform (SIFT) algorithm to detect keypoints in the cover image and K-means clustering to group the detected keypoints into clusters. The secret message is then encoded using quantum circuits, and a NEQR code is created for the message. The NEQR code is embedded in the cover image by modifying the cluster centers' pixel values. This quantum error-correcting code can be used to protect secret messages from noise. The stego image is then created by combining the modified cover image with the NEQR code. The scheme was implemented using the Python programming language and the qiskit library. We evaluated our steganography system regarding imperceptibility and robustness using several metrics. Our experimental results show that our system achieves high imperceptibility as measured by PSNR, SSIM, and histogram analysis. The system also achieves high robustness as measured by BER. Our steganography system provides a novel and practical approach to hiding secret messages in images with high imperceptibility and robustness. The system has potential applications in secure communication and data hiding.

## References

[1] Mastriani, M. (2021). Fourier's Quantum Information Processing. *SN COMPUT. SCI.*, 2, 122.

[2] Dendukuri, A., & Luu, K. (2018). Image processing in quantum computers. *arXiv preprint arXiv:1812.11042*.

[3] Wang, M. X., et al. (2022). A novel quantum color image steganography algorithm based on turtle shell and LSB. *Quantum Information Processing*, 21(4), 148.

[4] Zhou, R. G., et al. (2018). A novel quantum image steganography scheme based on LSB. *International Journal of Theoretical Physics*, 57, 1848-1863.

[5] Lim, Jeonghun, and Kunwoo Lee (2019). 3D object recognition using scale-invariant features. In *The Visual Computer* (Vol. 35), 71-84.

[6] Ezugwu, Absalom E., et al. (2022). "A comprehensive survey of clustering algorithms: State-of-the-art machine learning applications, taxonomy, challenges, and future research prospects. In *Engineering Applications of Artificial Intelligence*, 110, 104743.

[7] Li, P., & Lu, A. (2018). LSB-based steganography using reflected gray code for color quantum images. *International Journal of Theoretical Physics*, 57(5), 1516-1548.

[8] DiAdamo, S., et al. (2022). Practical Quantum K-Means Clustering: Performance Analysis and Applications in Energy Grid Classification. *IEEE Transactions on Quantum Engineering*, 3, 1-16.

[9] Poggiali, A., et al. (2022). Quantum Clustering with k-Means: a Hybrid Approach. *arXiv preprint arXiv:2212.06691*.

[10] Luo, J., et al. (2019). A novel quantum steganography scheme based on ASCII. *International Journal of Quantum Information*, 17(04), 1950033.

[11] Witten, D. M., & Tibshirani, R. (2010). A framework for feature selection in clustering. *Journal of the American Statistical Association*, 105(490), 713-726.

[12] Zhang, Y., et al. (2013). NEQR: a novel enhanced quantum representation of digital images. *Quantum Information Processing*, 12, 2833-2860.

[13] Cohen, G., et al. (2017). EMNIST: Extending MNIST to handwritten letters. In *2017 international joint conference on neural networks (IJCNN)*.

[14] Marti, U. V., & Bunke, H. (2002). The IAM-database: an English sentence database for offline handwriting recognition. *International Journal on Document Analysis and Recognition*, 5, 39-46.

[15] Liu, C. L., et al. (2011). CASIA online and offline Chinese handwriting databases. In *2011 international conference on document analysis and recognition*.

[16] Lou, D. C., & Sung, C. H. (2004). A steganographic scheme for secure communications based on the chaos and Euler theorem. *IEEE Transactions on Multimedia*, 6(3), 501-509.

[17] Wang, Z., Simoncelli, E. P., & Bovik, A. C. (2003). Multiscale structural similarity for image quality assessment. In *The Thirty-Seventh Asilomar Conference on Signals, Systems & Computers, 2003* (Vol. 2).

[18] Burie, J. C., Ogier, J. M., & Loc, C. V. (2017). A spatial domain steganography for grayscale documents using pattern recognition techniques. In *2017 14th IAPR International Conference on Document Analysis and Recognition (ICDAR)* (Vol. 9).

[19] K. P. Sinaga and M. -S. Yang (2020), Unsupervised K-Means Clustering Algorithm, *in IEEE Access, doi: 10.1109/ACCESS.2020.2988796.*,vol. 8, pp. 80716-80727

[20] Sammut, Claude, and Geoffrey I (2020). Webb, eds, In *Encyclopedia of machine learning. Springer Science & Business Media*

[21] Pardo, Scott, and Scott Pardo (2020). "Multivariate Analysis and Classification." *Statistical Analysis of Empirical Data: Methods for Applied Sciences*, 209-217. https://doi.org/10.1007/978-3-030-43328-4_16

[22] Nousi, P., & Tefas, A. (2020). Self-supervised autoencoders for clustering and classification. *Evolving Systems*, 11(3), 453-466.

[23] Na, S., Xumin, L., & Yong, G. (2010). Research on k-means Clustering Algorithm: An Improved k-means Clustering Algorithm. In *2010 Third International Symposium on Intelligent Information Technology and Security Informatics* (pp. 63-67).

[24] Lindeberg, T. (2012). Scale invariant feature transform. *2012: 10491*.

# Development of Interactive Data Visualization System in Three-Dimensional Immersive Space

Shah Murtaza Rashid Al Masud, Homaira Adiba, Tamzid Hossain, Aloke Kumar Saha, Rashik Rahman*

Computer Science and Engineering, University of Asia Pacific, Dhaka, Bangladesh

*Abstract*—Today's data-driven environments require innovative tools and methods to analyze and present data. The growth of data across many domains and remarkable technological advances have necessitated a shift from 2D data representations. The rapid growth in dataset scale, variety, and speed has revealed the limitations of conventional charts and graphs. Significant progress has been made in the domain of interactive, three-dimensional data visualizations as a means to address this challenge. The integration of Virtual Reality (VR) and Augmented Reality (AR) technologies enables users to achieve a heightened level of immersion in a simulated environment, where data is transformed into physical and interactive creatures. Recent research in the domain of immersive analytics has provided evidence that virtual reality (VR) and augmented reality (AR) technologies possess the capacity to provide succinct multiple layouts, facilitate collaborative data exploration, enable immersive multiview maps, establish spatial environments, enhance spatial memory, and enable interactions in three dimensions. The primary aim of this research is to design and implement a sophisticated data visualization system that integrates the development of a data pipeline within the Unity 3D framework, with the specific goal of aggregating data. The resulting system will enable the presentation of data from CSV files within a three-dimensional immersive environment. The prospective ramifications of this development have the capacity to yield good effects in diverse domains, including E-commerce analysis, financial services, engineering technology, medical services, data analysis, and interactive data display, among others. The proposed system presents a methodical framework for the development of a 3D data visualization system that integrates virtual reality (VR) technologies, Unity, and Python, with the aim of redefining the process of data exploration within a VR environment. This paper examines the integration of continuous testing methodologies within the context of Python API and virtual reality (VR) environments. It also allows for the creation of an interesting and immersive experience that meets user needs.

*Keywords*—*Immersive space; data visualization; VR system; python API; unity 3D*

## I. Introduction

The need for reliable tools and cutting-edge methodologies to analyze, assess, and present datasets has witnessed a substantial increase in the modern era. Technology and the availability of massive data sources across many disciplines enabled the growth. Two-dimensional (2D) charts and graphs are inadequate for revealing intricate patterns and relationships in increasingly large and complex datasets. As the quantity, variety, and speed of data continue to expand at an exponential rate, this constraint becomes more evident.

To address the aforementioned formidable task, significant progress has been made in the field of three-dimensional (3D) interactive data visualization systems. The emergence of these novel technologies has facilitated the ability of researchers, analysts, and other professionals to fully immerse themselves in a domain where data points are converted into tangible entities that can be actively engaged with. The current transformation is helped by the combination of augmented reality (AR) and virtual reality (VR) technologies, which allow individuals to interact with data in a way that is both intuitive and fascinating. Recent studies have shown the significant benefits that virtual reality (VR) and augmented reality (AR) can potentially provide in certain data exploration scenarios, as demonstrated by the existing collection of research in the field of immersive analytics in recent times. The advantages mentioned above encompass a diverse array of subjects, such as the utilization of small multiple layouts [1], the facilitation of collaborative data exploration [2]–[6], the implementation of immersive multiview map systems [4], [7], the provision of boundless spatial environments [1], [7], [8], grouping (clustering) and spatial (dimension reduction) [9], [10], the enhancement of spatial memory retention [11], and the enablement of three-dimensional spatial interactions [3], [10], [12], among various other benefits.

The primary objective of this research endeavor is to introduce and showcase an advanced data visualization system that effectively harnesses the vast capabilities of a three-dimensional immersive environment. This objective is achieved through the integration of computer graphics, data visualization, and human-computer interaction in a mutually advantageous manner. The objective is to provide an extensively interactive setting that facilitates the exploration and analysis of data beyond the limitations imposed by conventional two-dimensional representations. By providing users with the ability to deeply engage with the data, this novel technology aims to exceed the constraints of traditional visualization methods, therefore enhancing users' understanding and facilitating informed decision-making.

The contribution of the research paper can be summarized as follows:

- The proposed system effectively accomplishes the objective of developing a superior user interface within the domain of 3D data visualization, thus attaining excellence in this field. By blending simplicity and accessibility, people of all backgrounds and technological abilities may easily interact with data in an immersive 3D setting. This work serves to enhance the inclusivity and user-friendliness of data visualization.

- The presentation and implementation of advanced visualization techniques tailored for three-dimensional (3D) scenarios have made a significant and noteworthy

contribution. The application of customized visualization methods enhances the representation of complex data relationships and patterns that could otherwise provide difficulties in their recognition. This feature enables users to gain valuable insights from their data within a three-dimensional framework.

- The proposed system facilitates an enhanced level of interactivity by incorporating a wide range of interactive components. This enables users to actively engage with and examine real-time data within a fully immersive 3D setting. The incorporation of functionalities such as data filtering, grouping, and linking facilitates users in effectively managing and analyzing their datasets. The significance of this work resides in the provision of robust tools that enable users to manipulate and explore data effectively within a three-dimensional (3D) spatial context.

- The research work provides a practical contribution by elucidating the process of integrating a Python application programming interface (API) for the purpose of aggregating data into the Unity 3D development environment. This interface enables the smooth conversion of data from a Comma-Separated Values (CSV) file into a three-dimensional (3D) visualization environment, thereby augmenting the level of immersion and engagement. This study focuses on a crucial element of data transmission, aiming to facilitate a seamless and effective transfer from two-dimensional data sources to three-dimensional representation.

The subsequent sections of the document are organized in the following manner: Section II provides an overview and analysis of the existing literature and research studies that are relevant to the topic. The approach adopted is outlined in Section III, while Section IV gives a detailed explanation of the dataset. Section V provides a detailed explanation of the experimental configuration and the methodology employed for interacting with the data. Section VI provides an in-depth look of qualitative results, while Section VII encompasses the concluding remarks. Additionally, Section VIII outlines our upcoming research in this field. The remaining section consists of acknowledgment and references.

## II. RELATED WORKS

Numerous research inquiries have been conducted in the realm of immersive technologies and data visualization, thereby enhancing our comprehension of the various facets and potentialities of this emerging topic. The comprehensive and innovative research carried out over a prolonged period has greatly clarified the numerous applications of immersive technology and its ramifications across several fields of study. This summary offers a brief outline of the significant contributions made by researchers in these studies, clarifying their primary discoveries and ramifications.

In 2017, Ens, Barret [8] introduced the concept of Situated Analytics Interfaces (SAIs) on Head-Worn Displays (HWDs). Their groundbreaking work clarified the advantages of SAIs over traditional mobile interfaces as well as the implementation difficulties present in this developing field. In 2019, Taehoon K. *et al.* [13] conducted a thorough investigation

of the effectiveness of 3D immersive stereoscopic virtual reality technology in producing tactile sensations. Their research produced a significant finding: when compared to the haptic 3D visualization method shown on traditional 3D flat screens, the haptic 3D visualization method presented in a 3D stereoscopic space through headsets displayed superior qualities of intuitiveness, accuracy, and immersion. This result highlighted the immersive technology's transformative potential in boosting sensory engagement with data. Utilizing this knowledge, Alfaro, Luis, *et al.* [14] investigated the state-of-the-art immersive technologies, exploring their significant contributions to the creation of cognitive knowledge. Their research emphasized the potential for immersive technology to completely transform pedagogical methods while illuminating the crucial role it plays in the creation of teaching and learning activities.

Liu *et al.* [1] thorough investigation of the functionality and preferences of various tiny multiples layouts in immersive settings was carried out in the following year of 2020. Their thorough analysis, which covered designs including Flat, Quarter-Circle, and Half-Circle, with a focus on easing combinatorial difficulties through horizontal curvature, yielded insightful results. Their meticulous study did, however, recognize the intricacy of user preferences and performance in immersive tiny multiple visualizations and encourage further investigation of other elements. Simultaneously, Lee *et al.* [2] showed the benefits of utilizing shared surfaces and spaces in the cooperative field of data visualization. Their study emphasized how these collaborative environments create greater spatial awareness, increased collaboration, and improved communication. Lee and colleagues wisely understood the necessity for continued validation and further uses of shared surfaces and spaces in addition to their findings. In-depth research on immersive multiview map systems was conducted by Satriadi, K. A. *et al.* [7], who clarified their potential advantages for tasks including map browsing, search, comparison, and route-planning. While they correctly stressed the need for more study to support their findings and compare the effectiveness of immersive multiview maps to conventional single-view exploration techniques, their observations shed light on the exciting prospects of these systems.

Shifting the focus to navigation strategies in virtual worlds, Yang, Y. *et al.* [15] investigated the effectiveness of two different approaches: overview+detail and zooming in 3D scatterplots. Their comparison investigation, which covered four situations, shed light on the subtle differences between user engagement and comprehension in immersive environments. Yang, Y. *et al.* [3] research on visualization techniques was expanded upon, notably about the use of area-linked data in immersive settings. They gave important insights into the relative efficacy of conventional 2D choropleth maps versus 3D prism maps and colorful prism maps in virtual reality (VR) through thorough controlled tests.

The study of the difficulties in this new field by Ens, B. *et al.* [16] in 2021 was a turning point in the development of immersive analytics. Incorporating visualization, immersive environments, and human-computer interaction, their article covered 17 different difficulties that were categorized into four main categories. These difficulties paved the way for additional research and advancement in the area of immersive

analytics. The dynamics of collaboration modes and user position arrangements in a VR learning environment supporting immersive collaborative tasks were investigated concurrently by Chen, L. *et al.* [17] Their findings suggested that in cooperative VR learning settings, shared views and particular user locations could significantly improve task performance and user experience.

Reichherzer *et al.* [11] conducted a study in the field of law to explore the potential applications of immersive virtual reconstructions, particularly virtual reality (VR), in aiding juries during trial hearings. The study unveiled fascinating possibilities for the integration of immersive technology inside the court system. Newbury *et al.* [12] conducted a research investigation on the concept of embodied engagement in immersive maps. Their study shed light on the perceptual intricacies associated with maps as objects in three-dimensional space, as well as the utilization of consistent physical principles during the process of map design.

In the year 2022, Luo, W. *et al.* [18] initiated a scholarly discourse concerning the transformative capacity of augmented reality (AR) in reshaping forthcoming work environments. The researchers conducted a meticulous investigation on the impact of office environments and work practices on the organization of virtual material, specifically about the process of sensemaking using augmented reality. Liu *et al.* [19] conducted a comprehensive examination of immersive approaches for interactive Information Visualization (InfoVis), including diverse data kinds. The user did not provide any text to rewrite. The researchers' findings indicated potential shifts in data browsing behaviors through a comparison of immersive and non-immersive data visualization methods. It is hypothesized that non-immersive approaches may supplant immersive techniques in handling extensive data sets.

The aforementioned collaborative efforts exemplify a diverse array of research initiatives that have contributed to the discourse around immersive technologies and data visualization. These endeavors have yielded valuable insights, shedding light on many aspects of this rapidly evolving field and paving the way for novel avenues of investigation.

## III. METHODOLOGY
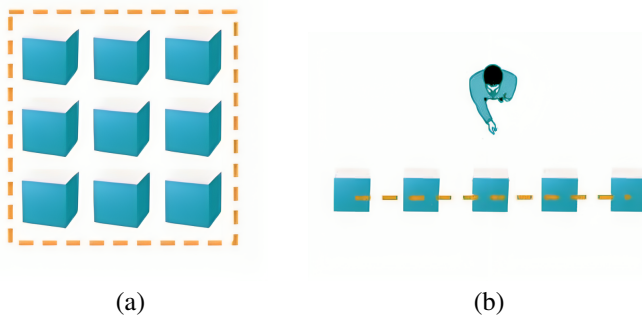


Fig. 1. (a) 2D DataBlocks and (b) 3D Immersive Space View

The principal methodology adopted in this research involves the development and application of a three-dimensional data visualization system. To address this matter, a block dimension and a layout design have been devised. The chosen configuration for the immersive area depicted in Fig. 1 involves a 2D block dimension and a 3D horizontal layout design. This arrangement aims to expand the possibilities for interactive data exploration and analysis within the dynamic realm of a 3D immersive environment. The aforementioned methodology signifies a fundamental change in our strategies for interacting with and deriving insights from intricate datasets, hence creating a significant impact on the field of data visualization. The system makes use of the Meta Quest 2 virtual reality (VR) headset, which has been specifically created to use the Python API and Unity software in order to provide data in a visually realistic manner.

As depicted in Fig. 2, the methodology is structured into three discrete subsections, each of which centers on a crucial facet of the system's development and implementation. The subsections are the following:

*1) Python API:* The utilization of a data backend API is used to streamline the process of data processing and retrieval. The Pandas library, which is a powerful tool for manipulating data, is employed to do data processing. The utilization of Flask, a web framework, is incorporated into the codebase to facilitate the transformation of the processed data into an API that can be effectively utilized. JSON (JavaScript Object Notation) is widely regarded as the optimum format for efficient data interchange, particularly for rapid data transportation.

The data frame is imported from a CSV file, serving as the primary data source. The Flask framework hosts two distinct APIs inside a single application. The first API offers a compilation of numeric data columns that may be plotted and are easily accessible. The inclusion of a user-defined column as a route parameter in the second API streamlines the process of user-driven data selection.

Upon completion of the data aggregation process, the selected column becomes linked to the predetermined column labeled "Major Category". The plot data gathered and given consists of aggregated data points, which comprise the necessary index values for constructing a bar plot. The accumulated data is advantageous in determining the relative proportions for pie charts.

The primary objective of these API is to collect and analyze data before transmitting it to the Unity platform to generate graphical representations.

*2) Unity Development:* Within the Unity environment, the utilization of 3D prefabricated objects is employed to graphically represent bar charts and pie charts in a manner that is highly compatible with the VR context. The prefabricated structures serve as the foundational framework for the representation and interpretation of data within the immersive virtual reality setting. The data acquired from the Python application programming interfaces (APIs) is dynamically integrated into the Unity project at runtime. The process of accessing pertinent data is expedited through the utilization of user-input columns as integral elements within URLs. The data acquired through the application programming interface (API) is associated with the pre-existing objects within the Unity software environment. A dictionary is employed as a data structure to aid the organizing of data by establishing a relationship between columns and their related values. The
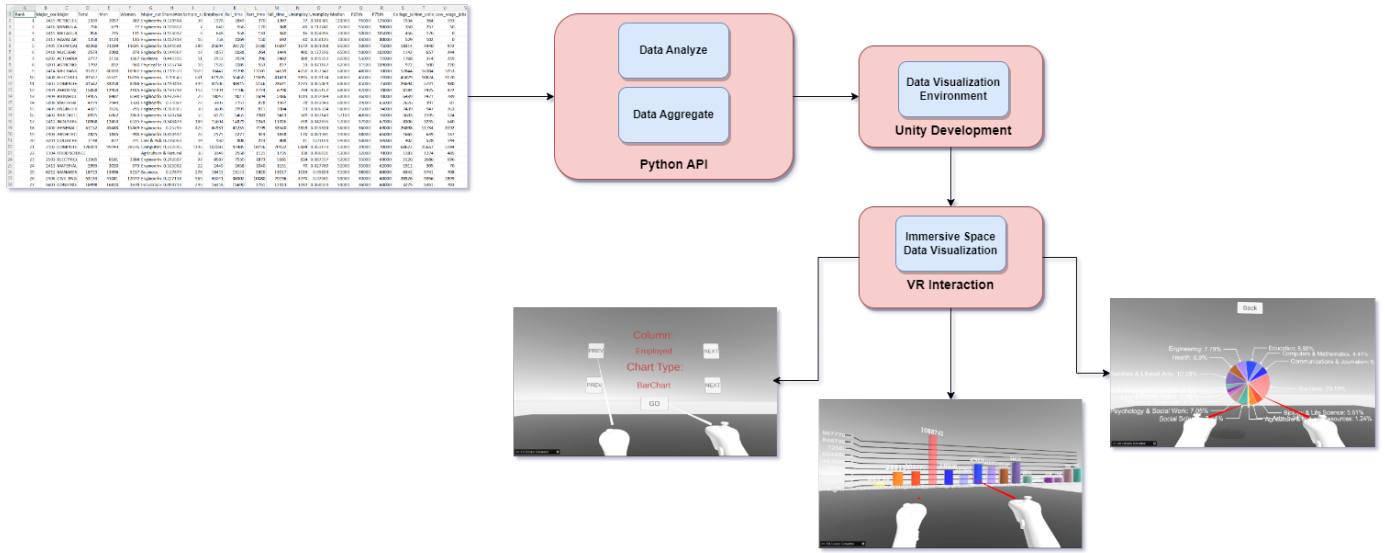
Fig. 2. Proposed data flow and unity visualization model in immersive space.

utilization of data mapping is employed in order to ensure that the preconstructed three-dimensional representations accurately and efficiently display the selected data. Ultimately, this process reaches its completion in the production of the expected data visualizations.

*3) VR Interaction:* The incorporation of Virtual Reality (VR) technology into the Unity project represents a crucial milestone in the pursuit of creating a fully immersive data visualization experience. The project has been designed to facilitate VR interactions, with a specific emphasis on the Oculus VR platform. The incorporation of VR controllers serves to augment the user's experience within the immersive environment. The XR Interaction Toolkit plays a crucial role in enabling virtual reality interactions and behaviors. The process of continuously testing and gathering feedback from users is of utmost importance in the iterative refinement of a system, as it aids in enhancing its usability and alignment with the desired objectives. The use of the Oculus VR platform is employed for the implementation of the data visualization project that relies on virtual reality technology, guaranteeing compatibility and achieving optimal performance inside the virtual reality environment.

This study presents a systematic approach to developing a 3D data visualization system that effectively combines Python API, Unity, and VR technologies. This methodology aims to offer a new and efficient way of data exploration and presentation inside a virtual reality setting by employing meticulous data processing, dynamic data transmission, and immersive visualization techniques. The process of continuous testing and refining plays a crucial role in ensuring that the system remains in line with user expectations and provides a captivating immersive experience.

## IV. Dataset

The dataset included in this study is derived from an article entitled "The Economic Guide to Picking a College Major", accessible on the well-recognized data-centric platform 538.

The information under consideration offers significant statistical insights into the median incomes linked with different college degrees. The dataset utilized in this study was carefully selected and retrieved from the previously stated publication. It serves as a solid basis for the empirical analysis conducted in this research. The dataset is supplied in the well-recognized CSV format and was obtained from a publicly accessible GitHub repository[1].

A notable characteristic of this dataset is its specific emphasis on individuals who have just completed their education. The intentional emphasis on individuals who have just completed their education is supplemented by the incorporation of gender-specific data, making it a highly beneficial tool for undertaking a thorough and diverse investigation.

The dataset illustrates the substantial financial disparities that might arise as a result of selecting a certain academic degree. It contains a thorough structure consisting of 21 attributes and 173 rows, providing a wealth of information about the economic aspects of college major choices. The structural complexity of the dataset not only facilitates a comprehensive analysis of median wages but also facilitates the identification of possible patterns and complexities that may arise among different academic disciplines, particularly among those who have just graduated from college.

## V. VR Prototype Implementation

The virtual reality prototype that has been constructed in this study serves as a tool for investigating the design aspects of immersive spatial data display.

### A. Experimental Setup

In our study, we employed the Oculus Meta Quest 2, a room-scale VR device, together with the Unity version 2021.3.16f1. The prototype operates on a personal computer

---

[1]https://github.com/fivethirtyeight/data/tree/master/college-majors

running the Windows 10 operating system. The computer is equipped with an Intel(R) Core(TM) i7-7500U CPU, which has a clock speed of 2.70GHz and can reach a maximum speed of 2.90GHz. The prototype also utilizes VRTK XR interaction to enable interactive components.

### B. Interacting with the data

The proposed system aims to combine a framework for visualizing three-dimensional data with a virtual reality system. The system provides users with a menu-based interface that allows them to select attributes from a dataset stored in a CSV file. Users can also choose the required chart styles to visualize their data in a personalized manner. The user's input demonstrates a connection between the Python API and a specific attribute called "Major Category".

This feature serves to identify the main fields of study undertaken by graduates. To improve the narrative coherence, it is important to employ a consistent structural element. Based on the provided options, the aggregate data is utilized to generate the required charts.

## VI. RESULT AND DISCUSSION

This section presents the findings of this particular research study. Based on the information provided in Section IV, it can be inferred that the dataset under consideration pertains to recent graduates, encompassing 21 attributes and 173 rows. We chose to analyze the qualities of "Employed" and "Full-time" employed among the graduates and represented the data using both a bar chart and a pie chart.

Within this system, the user has the ability to choose a certain column and chart type based on their preferences.

In Fig. 3, the user chooses the "Employed" column and selects the Bar Chart type. This option leads to the creation of a Bar chart plot, as seen in Fig. 4.
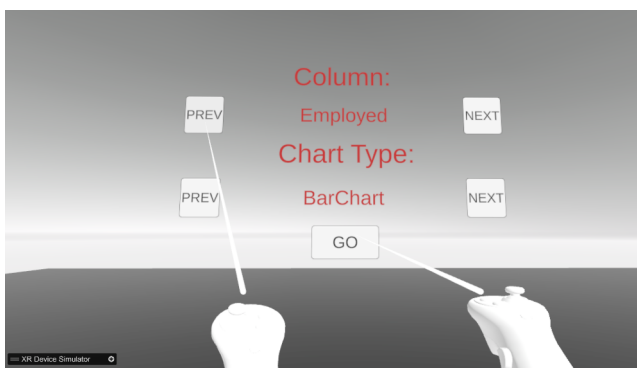


Fig. 3. Selecting employed column and bar chart type.

In Fig. 5, the user opted for the same column as previously and selected a different chart style, namely, a pie chart. Consequently, Fig. 6 displays the final plot in the form of a pie chart.

In Fig. 7, the user opted for the "Full-time" column and picked the Bar Chart type. Subsequently, Fig. 8 displays the outcome in the form of a Bar chart.
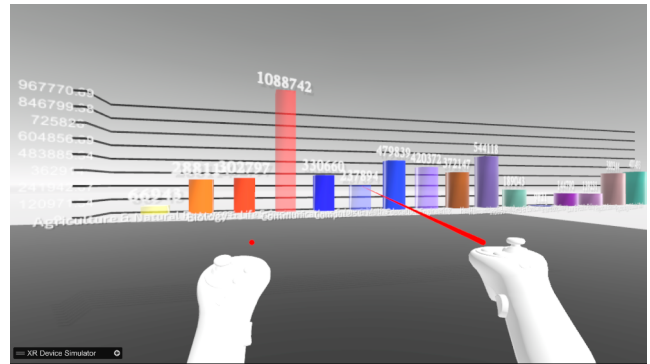


Fig. 4. Bar chart for employed graduates.
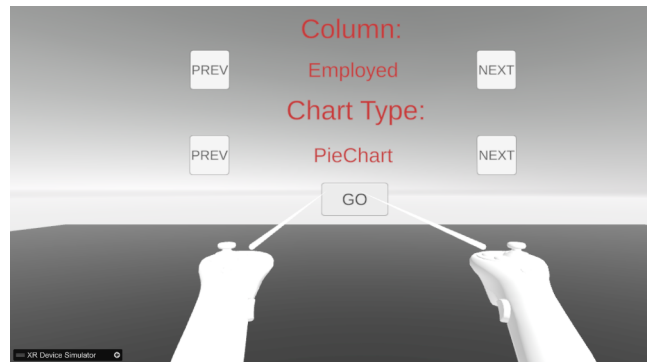


Fig. 5. Selecting "employed" column and pie chart type.
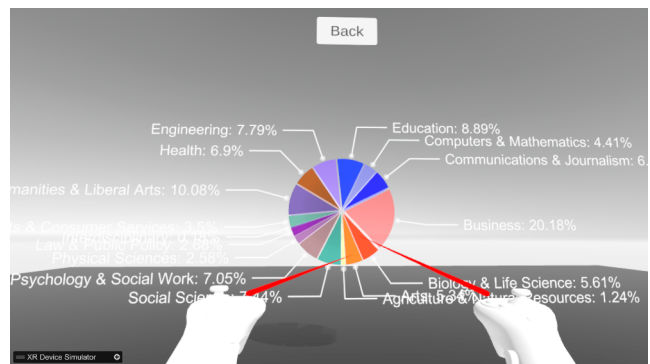


Fig. 6. Pie chart for employed graduates.

In Fig. 9, the user selected the Pie Chart type using the same column as previously. Subsequently, Fig. 10 displays the outcome in the form of a Pie chart.

## VII. CONCLUSION

With the swift progression of technology, our research has effectively made the transition from conventional two-dimensional (2D) data representations to immersive three-dimensional (3D) data visualization. The solution we have developed provides users with an interactive platform, that allows them to access and visualize datasets within a 3D immersive environment using Python APIs. The objectives have been successfully achieved through the expansion of
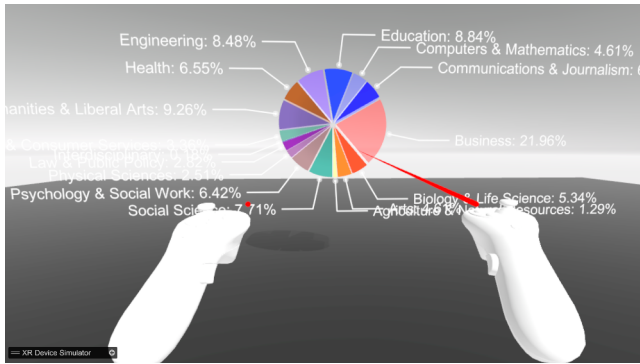
Fig. 10. Pie chart for full-time employed graduates.
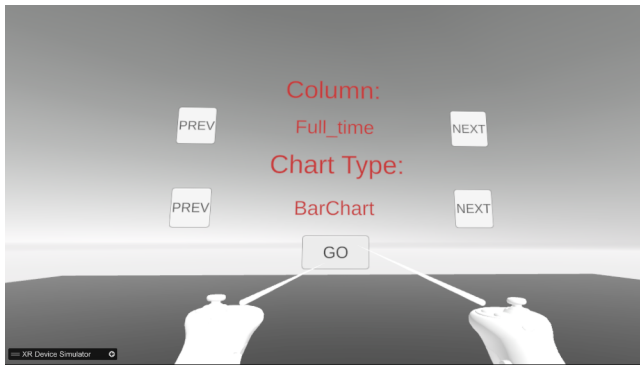


Fig. 7. Selecting "full-time" column and bar chart type.
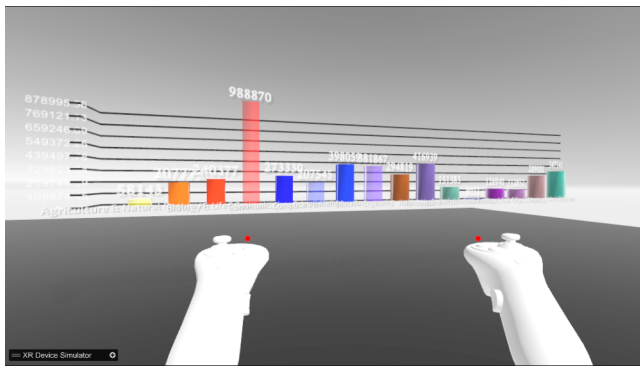


Fig. 8. Bar chart for full-time employed graduates.
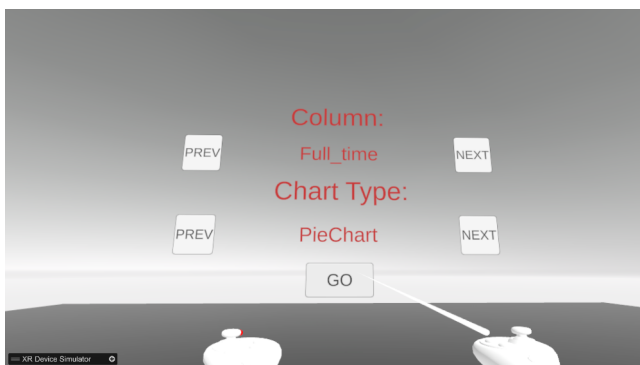


Fig. 9. Selecting "full-time" column and pie chart type.

interactive data exploration opportunities within the dynamic 3D immersive arena.

## VIII. Future Work

Our forthcoming study intends to improve the visualization of data by integrating a broader array of interactive chart formats. Furthermore, our objective will be to promote collaboration through the establishment of a communal immersive environment that enables multiple users to engage in data exploration and analysis concurrently.

## Acknowledgment

## References

[1] J. Liu, A. Prouzeau, B. Ens, and T. Dwyer, "Design and evaluation of interactive small multiples data visualisation in immersive spaces," in *2020 IEEE conference on virtual reality and 3D user interfaces (VR)*. IEEE, 2020, pp. 588–597.

[2] B. Lee, X. Hu, M. Cordeil, A. Prouzeau, B. Jenny, and T. Dwyer, "Shared surfaces and spaces: Collaborative data visualisation in a co-located immersive environment," *IEEE Transactions on Visualization and Computer Graphics*, vol. 27, no. 2, pp. 1171–1181, 2020.

[3] Y. Yang, T. Dwyer, K. Marriott, B. Jenny, and S. Goodwin, "Tilt map: Interactive transitions between choropleth map, prism map and bar chart in immersive environments," *IEEE Transactions on Visualization and Computer Graphics*, vol. 27, no. 12, pp. 4507–4519, 2020.

[4] A. Kunert, T. Weissker, B. Froehlich, and A. Kulik, "Multi-window 3d interaction for collaborative virtual reality," *IEEE transactions on visualization and computer graphics*, vol. 26, no. 11, pp. 3271–3284, 2019.

[5] T. Sun, Y. Ye, I. Fujishiro, and K.-L. Ma, "Collaborative visual analysis with multi-level information sharing using a wall-size display and see-through hmds," in *2019 IEEE Pacific Visualization Symposium (PacificVis)*. IEEE, 2019, pp. 11–20.

[6] C. Liu, O. Chapuis, M. Beaudouin-Lafon, and E. Lecolinet, "Shared interaction on a wall-sized display in a data manipulation task," in *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems*, 2016, pp. 2075–2086.

[7] K. A. Satriadi, B. Ens, M. Cordeil, T. Czauderna, and B. Jenny, "Maps around me: 3d multiview layouts in immersive spaces," *Proceedings of the ACM on Human-Computer Interaction*, vol. 4, no. ISS, pp. 1–20, 2020.

[8] B. Ens and P. Irani, "Spatial analytic interfaces: Spatial user interfaces for in situ visual analytics," *IEEE computer graphics and applications*, vol. 37, no. 2, pp. 66–79, 2016.

[9] J. Wenskovitch and C. North, "An examination of grouping and spatial organization tasks for high-dimensional data exploration," *IEEE Transactions on Visualization and Computer Graphics*, vol. 27, no. 2, pp. 1742–1752, 2020.

[10] B. Bell, S. Feiner, and T. Höllerer, "View management for virtual and augmented reality," in *Proceedings of the 14th annual ACM symposium on User interface software and technology*, 2001, pp. 101–110.

[11] C. Reichherzer, A. Cunningham, T. Coleman, R. Cao, K. McManus, D. Sheppard, M. Kohler, M. Billinghurst, and B. H. Thomas, "Bringing the jury to the scene of the crime: Memory and decision-making in a simulated crime scene," in *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems*, 2021, pp. 1–12.

[12] R. Newbury, K. A. Satriadi, J. Bolton, J. Liu, M. Cordeil, A. Prouzeau, and B. Jenny, "Embodied gesture interaction for immersive maps," *Cartography and Geographic Information Science*, vol. 48, no. 5, pp. 417–431, 2021.

[13] T. Kim, C. Kim, H. Song, and M. Y. Sung, "Intuition, accuracy, and immersiveness analysis of 3d visualization methods for haptic virtual reality," *International Journal of Advanced Computer Science and Applications*, vol. 10, no. 11, 2019.

[14] L. Alfaro, C. Rivera, J. Luna-Urquizo, S. Alfaro, and F. Fialho, "Knowledge construction by immersion in virtual reality environments," *International Journal of Advanced Computer Science and Applications*, vol. 10, no. 12, 2019.

[15] Y. Yang, M. Cordeil, J. Beyer, T. Dwyer, K. Marriott, and H. Pfister, "Embodied navigation in immersive abstract data visualization: Is overview+ detail or zooming better for 3d scatterplots?" *IEEE Transactions on Visualization and Computer Graphics*, vol. 27, no. 2, pp. 1214–1224, 2020.

[16] B. Ens, B. Bach, M. Cordeil, U. Engelke, M. Serrano, W. Willett, A. Prouzeau, C. Anthes, W. Büschel, C. Dunne *et al.*, "Grand challenges in immersive analytics," in *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems*, 2021, pp. 1–17.

[17] L. Chen, H.-N. Liang, F. Lu, J. Wang, W. Chen, and Y. Yue, "Effect of collaboration mode and position arrangement on immersive analytics tasks in virtual reality: a pilot study," *Applied Sciences*, vol. 11, no. 21, p. 10473, 2021.

[18] W. Luo, A. Lehmann, H. Widengren, and R. Dachselt, "Where should we put it? layout and placement strategies of documents in augmented reality for collaborative sensemaking," in *Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems*, 2022, pp. 1–16.

[19] R. Liu, M. Gao, L. Wang, X. Wang, Y. Xiang, A. Zhang, J. Xia, Y. Chen, and S. Chen, "Interactive extended reality techniques in information visualization," *IEEE Transactions on Human-Machine Systems*, vol. 52, no. 6, pp. 1338–1351, 2022.

# Fine-Grained Differences-Similarities Enhancement Network for Multimodal Fake News Detection

Xiaoyu Wu[1], Shi Li*[2], Zhongyuan Lai[3], Haifeng Song[4], Chunfang Hu[5]
College of Computer and Control Engineering, Northeast Forestry University, Harbin, China[1,2]
DeepVerse Technology (Shanghai) Ltd, ShangHai, China[3]
School of Electronics and Information Engineering, Taizhou University, Taizhou, China[4]
DeepVerse Technology (Shanghai) Ltd, ShangHai, China[5]

*Abstract*—The use of social media has proliferated dramatically in recent years due to its increasing reach and ease of use. Along with this enlarged influence of social media platforms and the relative anonymity afforded to content contributors, an increasingly significant proportion of social media is composed of untruthful or "fake" news. Hence for various reasons of personal and national security, it is essential to be able to identify and eliminate fake news sources. The automated detection of fake news is complicated by the fact that most news posts on social media takes very diverse forms, including text, images, and videos. Most existing multimodal fake news detection models are structurally complex and not interpretable; the main reason for this is the difficulty of identifying essential features which characterize fake social media posts, leading to different models focusing on multiple different aspects of the news detection task. In this paper, we show that contrasting the *different and similar* (DS) features of social media posts serves as an important identifying marker for their authenticity, with the consequence that we only need to direct our attention to this aspect when designing a multimodal fake news detector. To address this challenge, we propose the Fine-Grained Differences-Similarities Enhancement Network (FG-DSEN), which improves detection with a simple and interpretable structure to enhance the DS aspect between images and text. Our proposed method was evaluated on two different language social media datasets, Weibo in Chinese and Twitter in English. It achieved accuracies 3% and 3.8% higher than other state-of-the-art methods, respectively.

*Keywords—Fake news detection; social media; pre-training model; multimodal; transformer*

## I. INTRODUCTION

Despite the challenges posed by the pandemic and current economic climate, virtual social media platforms have flourished in recent years, resulting in a significant increase in information volume. A large number of consumers tend to acquire news exclusively through social media platforms instead of conventional sources. However, most platforms lack timely and effective supervision, making it easy for people to publish unverified news [1]. Furthermore, in contrast to the linear dissemination mode of traditional media, social media's dissemination characteristics facilitate the rapid spread of information, directly resulting in explosive growth of disseminated fake news and subsequently broader negative impacts with greater potential for social harm. Early research on fake news often used a vague definition that could include hoaxes, satires, or clickbaits as fake news. This study describes fake news as "news articles that are intentionally and verifiably false and could mislead readers" [2].

Apart from its rates of spread, social media news items are often multimodal and include text, images, and videos. Posts containing multimodal information are more appealing to readers, and studies have shown that news with images is, on average, 11 times more probable to be shared than text-only news [3]. However, the multimodal of most social media news items poses a significant obstacle to fake news detection [4]. The determination of news veracity based solely on text or images brings a challenge. Therefore, the development of models capable of integrating multimodal information is crucial for effective fake news detection.

Fake news has been a concern for researchers for some years. Due to the increasing realization of fake news' effects on society, work on fake news detection has dramatically intensified in recent years [5], [6]. With multimodal features proving effective in enhancing detection rates, so has research on fake news detection increasingly focussed on multimodal integration. Most multimodal methods involve feature interactions that are very complex, with multiple overlapping fusion modules, with the consequence that the final models are often very involved and are not amenable to extensions or improvements. This also leads to the difficulty in explaining these models, and it tends to neglect a very important feature of fake news: the differences and similarities between the text and image components of fake news [7]. This, in turn, contributes to the suboptimal performance of fake news detection. An emphasis on considering these differences and similarities can highlight distinctions between fake and real posts, thereby improving the discriminative power of the final classifier.

Based on these considerations and in contrast to most prevailing fake news detection networks, our work uses a simple structure to extract similar and dissimilar information among different modalities to enhance features and improve detection performance. Our structure is similar to the co-attention transformer [8], [9], but the performance is better. It can establish connections between similar and dissimilar points among features of different modalities while ensuring the purity of the original information to achieve the best detection performance. Earlier studies either overlooked this crucial connection or employed overly intricate interaction modules that compromised the integrity of the original information. The detection accuracy is at least 3% higher than the best method on two datasets.In concrete terms, we introduce the *Fine-Grained Differences-Similarities Enhancement Network (FG-DSEN)* to detect fake news. The architecture comprises four main components: two fine-grained feature extractors, a differences-

similarities enhancement network, and a fake news classifier. Our work makes the following contributions:

- We propose an effective detection method for fake news that emphasizes the differences and similarities (DS) between true and fake news items in terms of their textual and visual modalities. We find that these predominant features serve as accurate evaluation metrics for truthfulness. Our method avoids overcomplicating the task by requiring only text and image information.

- To effectively detect fake news via DS detection, we design a deep learning model called FG-DSEN. The proposed method extracts fine-grained features using an optimized pre-trained model. The differences-similarities information of these features are enhanced and used for classification, allowing the model to achieve higher accuracies than the baselines.

- We evaluate on two standard datasets and is able to achieve state-of-the-art performance on both. For purposes of comparison we have included a significant number of SOTA baselines from very recent works. We also perform extensive ablation studies on our model and conclude that its efficacy is indeed due to emphasis on the difference-similarity contrast of extracted news features.

The paper is structured into five sections. Section I provides an introduction to the study. Section II summarizes early research in the field. Section III provides a detailed description of the proposed methodology. Section IV covers the experimental aspect, including datasets introduction, parameter settings, comparative and ablation experiments, as well as corresponding result analysis. Finally, Section V concludes the work and discusses future directions.

## II. RELATED WORK

This study investigates approaches to detecting fake news using machine learning and deep learning methods, and additionally categorizing the latter into single-and multimodal methods.

### A. Machine Learning-based Fake News Detection

Early works on fake news detection typically employed hand-crafted features combined with machine learning models. Among the widely studied hand-crafted features are text-specific content features such as punctuation [10], [11], [12], textual sentiment polarity [3], [13], and personal pronouns [3], [10], [11]. Propagating features, such as the root degree in the propagation tree and the average degree of leaf nodes [3], [10], are significant indicators. User features like user's following and followed [3], [10], [12], [14] and account profile completeness [15]. These hand-crafted features can then be utilized to train machine learning models, including decision trees and SVMs. Castillo et al. [10] crawled hot news on Twitter for approximately two months and constructed a decision tree for news credibility determination. Pérez-Rosas et al. [11] manually curated features related to language, including punctuation, psycholinguistic features, and syntactic

rules. These methods necessitate researchers to possess extensive knowledge of linguistics and to know which features effectively distinguish true from false news, which is a difficult task.

### B. Deep Learning-based Fake News Detection

*1) Single-modal approaches to fake news detection:* With the advent of deep learning models, researchers have discovered that they outperform traditional machine learning models and no longer necessitate intricate hand-crafted features. Kaliyar et al. [16] introduced a deep convolutional neural network (FNDNet) for fake news detection, which takes as input a word embedding vector produced by GloVe. Sahoo et al. [17] present a technique for detecting the authenticity of news content by combining user profiles. The exBAKE model presented by Jwa et al. [18] uses weighted cross-entropy to classify the data, which mitigates the issue of data imbalance in BERT [19].

*2) Multimodal approaches to fake news detection:* News images contain abundant information, so an increasing number of researchers are focusing on fake news detection methods that fuse multimodal features. Singhal et al. [20] proposed Spotfake, a multimodal approach for detecting fake news, which employs VGG-19 to extract image features and BERT to extract textual features. Wang et al. [21] proposed an Event Adversarial Neural Network (EANN) that utilizes event discrimination as an auxiliary task. The att-RNN framework proposed by Jin et al. [22] leverages an attention mechanism to enhance modal information, integrates social context features, and feeds the fused multimodal information into the classifier for classification. Wu et al. [23] proposed a Multimodal Co-attentive Networks (MCAN), and Qian et al. [24] proposed a Hierarchical Multi-modal Contextual Attention Network (HM-CAN). Both approaches utilize transformer-based attention modules to combine features from various modalities or layers, thereby aiding detection. Jing et al. [25] presented a Multi-modal Progressive Fusion Networks (MPFN) to retain shallow information by sampling and fusing features at different levels. Although previous works have achieved superior results in fake news detection tasks, they neglected the extraction of fine-grained features and mapping alignment and failed to exploit similarities and differences of features when fusing in depth.

## III. METHODOLOGY

### A. Model Overview

The present study establishes the task of detecting fake news as follows: given a multimodal news post $S = (T, V)$ containing text $T$ and images $V$. Training a model then implies a mapping $f : S \rightarrow Y$, where our predefined classes $Y \in \{0, 1\}$ with $Y = 0$ implying that a news post $S$ is fake and $Y = 1$ implying that it is true. More details about the model will be provided in the later subsections.

The proposed FG-DSEN is shown in Fig. 1. The model consists of

- Two fine-grained feature extractors: We utilize the VGG-19 [26] and 1D convolution to extract fine-grained features from images; for text we employ BERT and a BiLSTM;

- A differences-similarities enhancement network: Two self-attention modules are applied in parallel to extract feature similarities and differences. The attention module is able to capture correlation between these;

- A fake news classifier: We connect a simple fully-connected feedforward network to perform classification of the fused features.
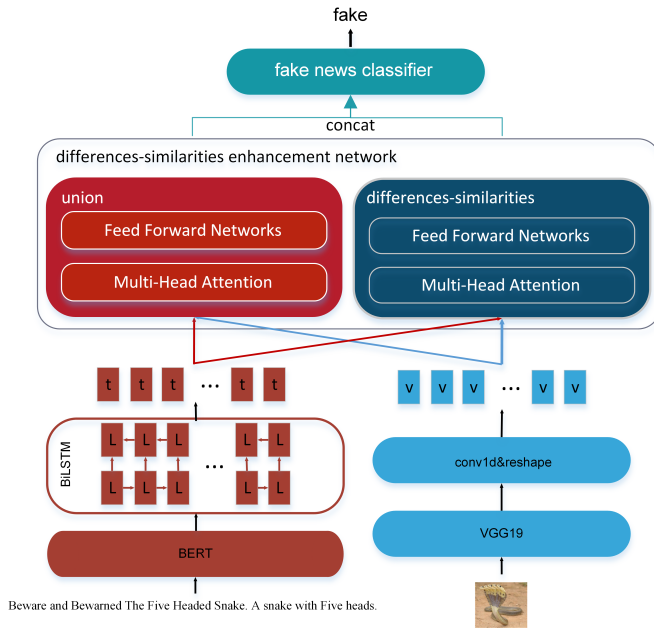


Fig. 1. The proposed model architecture.

### B. Text Feature Extractor

Fake news detection conventionally employs static word embedding models. In our case, in order to context information explicitly into account, we use a pre-trained BERT model which has excellent performance in dynamic word embedding tasks. Texts $T$ of social media news posts have the general structure $T_i = [x_1, x_2, \ldots, x_n]$, where $x_j \in T_i$, $j \in \{1, 2, \ldots, n\}$ is the $j$th word in the $i$th text corpus. We then obtain the dynamically extracted word vector, representing the fine-grained word-level features, via a BERT model. These are input into a BiLSTM to generate the text fine-grained feature $F^T$ containing global text information, as shown in Eq. (1).

$$F^T = \text{BiLSTM}\left(\text{BERT}\left(t_i; \Theta_{\text{BERT}}\right); \Theta_{\text{BiLSTM}}\right), \quad (1)$$

where $\Theta_{\text{BERT}}$ and $\Theta_{\text{BiLSTM}}$ are the BERT and BiLSTM model parameters, respectively.

### C. Image Feature Extractor

We utilize the VGG-19 as an image feature extractor by eliminating the average pooling and classification layers. We also remove the final 2D Max-pooling layer in the feature extraction part to reduce the loss of image information and facilitate alignment with text features. Image $i_j$ of news posts is input to the modified VGG-19 to obtain the fine-grained pixel-level features.

$$\mathbf{f}_{\text{VGG-19}} = \text{VGG-19}\left(V_j; \Theta_{\text{VGG-19}}\right) \quad (2)$$

Subsequently, these are aligned with text fine-grained features through reshaping and 1D convolution to obtain fine-grained image features, as shown in Eq. (3).

$$F^V = \text{Conv1d}\left(\text{Reshape}(\mathbf{f}_{\text{VGG-19}})\right). \quad (3)$$

### D. Differences-Similarities (DS) Enhancement Network

A differences-similarities (DS) enhancement network was designed based on ideas on feature processing involving fusion of fine-grained feature similarities and differences before classification [25]. Firstly, $F^T$ and $F^V$ are concatenated, as shown in Eq. (4). The direct concatenation of fine-grained features at the word-level and pixel-level is equivalent to modal alignment, hence establishing a link between word vector and feature map. Subsequently, a fully connected layer with the `LeakyReLU` activation function is applied to map the concatenated features into the same semantic space, as shown in Eq. (5).

$$F^{VT} = \text{Concat}(F^T, F^V) \quad (4)$$
$$P^{VT} = \max(0, W_F F^{VT}) + 0.01 * \min(0, W_F F^{VT}) \quad (5)$$

where $F^{VT}$ represents the stitching feature, $P^{VT}$ represents the stitching projection feature, and $W_F$ denotes the fully connected layer's weight. $F^T$ and $F^V$ are connected after subtracting and finding the Hadamard product, respectively, as shown in Eq. (6). Subtraction yields the different points between image and text features, while the Hadamard product amplifies the similar points of image and text features. Then a fully connected layer with the `LeakyReLU` activation function maps text and image differences-similarities features into the same semantic space, as shown in Eq. (7).

$$FC^{VT} = \text{Concat}((F^T - F^V), (F^T \odot F^V)) \quad (6)$$
$$PC^{VT} = \max(0, W_{FC} FC^{VT}) + 0.01 * \min(0, W_{FC} FC^{VT}) \quad (7)$$

where $FC^{VT}$ represents the differences-similarities feature, $PC^{VT}$ represents the differences-similarities projection feature, and $W_F$ denotes the fully connected layer's weight.

After deep-fusing $P^{VT}$ through the self-attention module, we obtain the union attention feature $S^U$. Similarly, $PC^{VT}$ is passed through another self-attention module to obtain the DS attention feature $S^C$. The DS attention feature is used to help distinguish fake news by interacting with the similar and dissimilar parts of the two modalities. The union attention feature then ensures that the original multimodal information is not lost after enhancement by the differences-similarities enhancement network to help the model comprehend the whole news. An example of obtaining a union attention feature is shown in Eq. (8)-(11).

$$S_1^U = \text{Softmax}\left(\frac{Q_U K_U^T}{\sqrt{d_k}}\right) V_U \quad (8)$$
$$S_2^U = \text{Layer\_norm}\left(P^{VT} + S_1^U\right) \quad (9)$$
$$FFN\left(S_2^U\right) = \max\left(0, W_1 S_2^U\right) W_2 \quad (10)$$
$$S^U = \text{Layer\_norm}(S_2^U + FFN\left(S_2^U\right)) \quad (11)$$

where $Q_U = P^{VT} W_Q, K_U = P^{VT} W_K, V_U = P^{VT} W_V$, This indicates that after inputting $P^{VT}$, the $Q_U, K_U, V_U$ required to calculate the self-attention are obtained by multiplying with

their respective weight matrices $W_Q, W_K, W_V$. The denominator in Eq. (8) is a scale factor controlling the magnitude of the attention fraction, where $d_k$ represents the dimension of Q. $W_1$ and $W_2$ are the two weight matrices in the position-wise feed-forward networks. `Layer_norm` refers to layer normalization. Finally, $S^U$ and $S^C$ are reconnected after mean-pooling to obtain the enhanced feature $S^{UC}$, as shown in Eq. (12).

$$S^{UC} = \texttt{Concat}(\texttt{MeanPooling}(S^U), \texttt{MeanPooling}(S^C)) \tag{12}$$

### E. Fake News Classifier

The fake news classifier employed in this study is a MLP consisting of two fully connected layers. The association between characteristics and classifications is accomplished via the softmax activation function applied to the output layer of the MLP upon feeding $S^{UC}$. This is demonstrated in Eq. (13) and (14).

$$MLP_1 = \max(0, W_{s1}S^{UC}) + 0.01 * \min(0, W_{s1}S^{UC}) \tag{13}$$

$$P = \texttt{Softmax}(W_P MLP_1 + b_P) \tag{14}$$

In the fully connected layer above, $W_{s1}$ and $W_P$ represent the weight matrix and $b_P$ represents the bias term. This study uses cross-entropy as the loss function.

## IV. EXPERIMENTS

This section presents the results of numerical experiments performed on our proposed model, evaluated on two well-known social media datasets (Weibo and Twitter). We introduce these datasets and discuss some state-of-the-art baseline models. Then FG-DSEN is compared with these methods and we show that it achieves SOTA results compared to the baselines. Finally we present results from ablation experiments and analyze and interpret the findings derived from our experiments.

### A. Datasets

- Twitter: The dataset [27] contains the text of news posts, additional images, and corresponding IDs, and includes a development and a test set. The former comprises about 5,000 real and 6,000 fake news posts. The latter contains about 2,000 news posts. We retained only those news samples that contained both text and images and used Google Translate to standardize the language of the tweets to English.

- Weibo: Jin et al. [22] collected and published this dataset. Fake news posts were sourced from all news articles published by the official Weibo platform disinformation system between May 2012 and January 2016, which had been verified as fake. The system enlists reputable users to review tweets reported by regular users to determine their veracity. The real news posts were sourced from posts verified by the official Xinhua News Agency. During dataset processing, we remove news samples containing only text or images in the dataset and eliminate duplicate or low-quality images. Table I presents detailed statistics for both datasets.

TABLE I. STATISTICS OF TWO DATASETS

| Dataset | Label | Number | Total |
|---|---|---|---|
| Weibo | Fake | 4749 | 9528 |
| | Real | 4779 | |
| Twitter | Fake | 7021 | 12995 |
| | Real | 5974 | |

TABLE II. DIFFERENT HYPERPARAMETERS ON TWO DATASETS

| Hyperparameter | Value | |
|---|---|---|
| | Weibo | Twitter |
| Sentence length | 192 | 87 |
| BERT vision | BERT_base_chinese | BERT_base_uncased |
| Minibatch size | 70 | 128 |
| Epoch | 150 | 100 |
| Learning rate | 0.00005 | 0.0001 |

### B. Data Preprocessing and Experimental Settings

Text sequences were converted to dynamic word vectors using BERT-base with a dimension of 768. For image data, we resized images to $224 \times 224 \times 3$ and fed them to the modified VGG-19 model for fine-grained feature extraction, yielding a dimensionality of 100352. We froze the parameters of both BERT and VGG-19 models to prevent overfitting. The BiLSTM had a dropout rate of 0.4 and a dimension of 256; the convolution kernel size of the 1D convolution is set to 1, with a stride of 1 and an output channel count equal to the length of the text sequence. The two transformer encoders of the self-attention module are identical, with dimensions of 256, 8 attention heads, and a dropout rate of 0.4. We optimize parameters utilizing the Adam optimizer. The hyperparameters that were different on the two datasets during training are presented in Table II.

### C. Evaluation

We compare FG-DSEN with other single- and multimodal methods to evaluate its performance on fake news detection tasks.

#### 1) Single-modal based approaches:

- Text: We omit the image embedding component from the FG-DSEN. After extracting text fine-grained features using BERT and BiLSTM and performing differences-similarities feature extraction, we input to a self-attention module and perform fake news classification via a MLP layer;

- Images: Similar to the processing of text-only news classification, we exclude the text embedding layer from the FG-DSEN and use VGG-19 and a Conv1d to extract fine-grained image features before directly feeding them into a self-attention module and MLP for classification.

#### 2) Multimodal-based approaches:

- Att_RNN [22]: Att_RNN is a recurrent neural network incorporating an attention mechanism for modal fusion in rumor detection. To ensure a fair comparison

with our approach, we utilize only text and image features in our experiments and remove the components that deal with social context information;

- EANN [21]: Event Adversarial Neural Networks(EANN) extract event-invariant features by adding an event discriminator as a secondary task to help better detect fake news. For our experiments, we utilize EANN with the event discriminator component removed;

- MVAE [28]: The Multimodal Variational Autoencoder (MVAE) consists of a bimodal variational autoencoder and a binary classifier. It employs pre-trained VGG-19 and BiLSTM to mine features from images and text;

- SpotFake [20]: SpotFake is a multimodal framework developed for the detection of fake news. The framework employs VGG-19 to extract image features and a pre-trained language model, BERT, to extract text features;

- SpotFake+ [29]: SpotFake+ is built on top of Spot-Fake, which utilizes a pre-trained XLNet model instead of BERT to extract text features and employs richer fully-connected layers to assist in modal fusion;

- SAFE [30]: SAFE is a multimodal fake news detection approach based on perceptual similarity. The framework introduces auxiliary objective functions to measure text and image similarity, aiding in detecting fake news by incorporating measures beyond simply splicing multimodal features together;

- HMCAN [24]: Hierarchical Multimodal Contextual Attention Network (HMCAN) captures hierarchical semantic information through a hierarchical coding network. Multimodal contextual attention networks are used to fuse inter-modality and intra-modality relationships;

- MPFN [25]: the Multimodal Progressive Fusion Network (MPFN) uses Swin Transformer to extract multi-level visual features from images, VGG-19 to extract additional frequency domain features from images, and BERT to extract text features.

### D. Results and Analysis

We conducted broad experiments on two public datasets to evaluate our model's effectiveness and generalization ability. Table III shows that the overall performance of the FG-DSEN surpasses that of the baseline approach. Based on these results, the following conclusions can be drawn:

- For both single-modal methods, neither perform as well as the original FG-DSEN. However, the text single-modal method's accuracy in the Weibo dataset surpasses all other multimodal methods except our proposed method. This demonstrates that text fine-grained features with the self-attention module are highly effective for news classification. Its accuracy in the Twitter dataset is second only to HMCAN, probably because the text in the Twitter dataset is short, and some of the text needs to be translated with

high quality, which impacts performance. The image single-modal approach has the lowest accuracy on the Weibo dataset. At the same time, it outperforms all multimodal approaches except our proposed method in the Twitter dataset, which proves that fine-grained image features with the self-attention module can sometimes be very effective;

- Both att-RNN and EANN methods exhibit diminished performance after excluding additional social background information and auxiliary tasks. This indicates that incorporating auxiliary tasks or additional features can enhance fake news detection performance. Nevertheless, the overall effect falls short of that achieved by a model designed specifically for various multimodal feature fusion;

- The inferior performance of MVAE compared to Spot-Fake demonstrates that the improvement brought by auxiliary tasks is not as effective as using pre-trained models. The fact that SpotFake is less effective than SpotFake+ suggests that using a better pre-trained model can enhance fake news detection;

- MPFN and HMCAN extract image and text features hierarchically and design a complex fusion network for hierarchical feature fusion abd therefore better utilizing shallow-level features. However, multiple complex fusion networks increase the computational cost and do not focus on the similarities and differences between different modal features, resulting in suboptimal detection of fake news;

- The Precision, Recall, and F1-Score of real and fake news on the Weibo dataset are equal for the FG-DSEN; we investigate them by confusion matrix, as presented in Table IV. We can see that the cause of the equivalence is that false positives and negatives happen to be equal;

- Our proposed method's overall performance on the Weibo and Twitter datasets surpasses other baselines, and additionally, We have a simple structure with fewer parameters to train. Therefore, our method extracts fine-grained features to better and more efficiently capture the images and text information in the news. The differences-similarities attention feature can better extract each modality's similar and dissimilar information. The union attention feature can ensure the fusion of the original multimodal information.

### E. Model Ablation

This section presents ablation experiments conducted on FG-DSEN and compares them with a variant using the co-attention transformer to determine its effectiveness.

- No transformer: The stitching projection features and differences-similarities projection features are connected and input to the fake news classifier for experiment ①;

- One transformer: We utilize a single self-attention module within the DS enhancement network. Three distinct experiments are conducted: ② inputting only

TABLE III. THE RESULTS OF DIFFERENT METHODS ON WEIBO AND TWITTER DATASET. THE HIGHEST SCORE IS HIGHLIGHTED IN BOLD

| Dataset | Methods | Accuracy | Fake news | | | Real news | | |
|---|---|---|---|---|---|---|---|---|
| | | | Precision | Recall | F1-Score | Precision | Recall | F1-Score |
| WEIBO | Textual only | 0.898 | 0.875 | **0.920** | 0.897 | **0.921** | 0.877 | 0.898 |
| | Visual only | 0.624 | 0.651 | 0.480 | 0.552 | 0.609 | 0.759 | 0.676 |
| | att-RNN | 0.772 | 0.854 | 0.656 | 0.742 | 0.720 | 0.889 | 0.795 |
| | EANN | 0.782 | 0.827 | 0.697 | 0.756 | 0.752 | 0.863 | 0.804 |
| | MAVE | 0.824 | 0.854 | 0.769 | 0.809 | 0.802 | 0.875 | 0.837 |
| | SpotFake | 0.869 | 0.877 | 0.859 | 0.868 | 0.861 | 0.879 | 0.870 |
| | SpotFake+ | 0.870 | 0.887 | 0.849 | 0.868 | 0.855 | 0.892 | 0.873 |
| | HMCAN | 0.885 | **0.920** | 0.845 | 0.881 | 0.856 | **0.926** | 0.890 |
| | MPFN | 0.838 | 0.857 | 0.894 | 0.889 | 0.873 | 0.863 | 0.876 |
| | FG-DSEN | **0.915** | 0.913 | 0.913 | **0.913** | 0.918 | 0.918 | **0.918** |
| TWITER | Textual only | 0.867 | 0.892 | 0.911 | 0.902 | 0.811 | 0.776 | 0.793 |
| | Visual only | 0.910 | 0.886 | **0.999** | 0.939 | **0.997** | 0.738 | 0.848 |
| | att-RNN | 0.664 | 0.749 | 0.615 | 0.676 | 0.589 | 0.728 | 0.651 |
| | EANN | 0.648 | 0.810 | 0.498 | 0.617 | 0.584 | 0.759 | 0.660 |
| | MAVE | 0.745 | 0.801 | 0.719 | 0.758 | 0.689 | 0.777 | 0.730 |
| | SpotFake | 0.771 | 0.784 | 0.744 | 0.764 | 0.769 | 0.807 | 0.787 |
| | SpotFake+ | 0.790 | 0.793 | 0.827 | 0.810 | 0.786 | 0.747 | 0.766 |
| | HMCAN | 0.897 | **0.971** | 0.801 | 0.878 | 0.853 | **0.979** | **0.912** |
| | MPFN | 0.833 | 0.846 | 0.921 | 0.880 | 0.809 | 0.721 | 0.740 |
| | FG-DSEN | **0.935** | 0.965 | 0.937 | **0.951** | 0.879 | 0.931 | 0.904 |
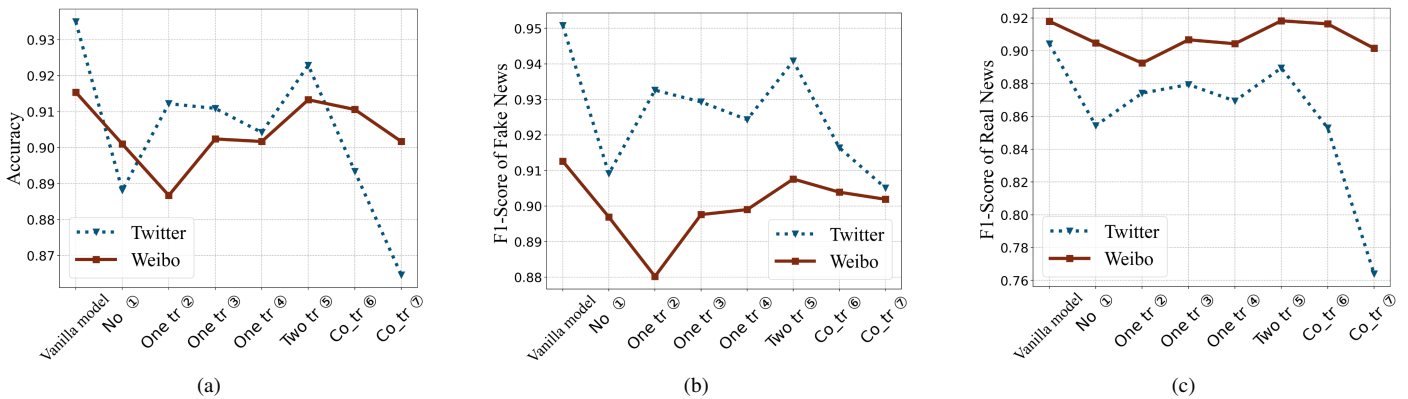


Fig. 2. Depicts the accuracy and F1-score of FG-DSEN and its variants on two datasets. The overall impact of the differences-similarities enhancement network is demonstrated.

TABLE IV. CONFUSION MATRIX OF OPTIMAL RESULTS OF FG-DSEN ON THE WEIBO DATASET

| Confusion Matrix | | Y true | |
|---|---|---|---|
| | | Positive | Negative |
| Y predicted | Positive | 694 | 62 |
| | Negative | 62 | 647 |

stitching projection features; ③ inputting only DS projection features; and ④ inputting features connected by stitching projection features and DS projection features;

- Two transformers: Within the DS enhancement network, we use two self-attention modules with shared weights for the experiment ⑤, otherwise identical to the original network;

- Co-attention transformer: Substitute the two parallel self-attention module structures within the DS enhancement network with a single co-attention transformer. We conduct two experiments: ⑥ inputting the stitching projection features and DS projection features into the co-attention transformer, respectively, and ⑦ inputting the text fine-grained features and image fine-grained features directly into the co-attention transformer after projecting them to the same dimen-

TABLE V. RESULTS OF ABLATION EXPERIMENTS OF FG-DSEN

| Dataset | Methods | Accuracy | Fake news | | | Real news | | |
|---|---|---|---|---|---|---|---|---|
| | | | Precision | Recall | F1-Score | Precision | Recall | F1-Score |
| WEIBO | FG-DSEN | **0.9154** | 0.9126 | 0.9126 | **0.9126** | 0.9180 | 0.9180 | 0.9180 |
| | No ① | 0.9010 | 0.9040 | 0.8900 | 0.8969 | 0.8983 | 0.9114 | 0.9048 |
| | One tr ② | 0.8867 | 0.9010 | 0.8604 | 0.8802 | 0.8744 | 0.9114 | 0.8925 |
| | One tr ③ | 0.9024 | 0.9113 | 0.8843 | 0.8976 | 0.8945 | 0.9193 | 0.9067 |
| | One tr ④ | 0.9017 | 0.8940 | 0.9041 | 0.8990 | 0.9091 | 0.8995 | 0.9043 |
| | Two tr ⑤ | 0.9133 | 0.9369 | 0.8801 | 0.9076 | 0.8936 | 0.9444 | **0.9183** |
| | Co_tr ⑥ | 0.9106 | **0.9419** | 0.8688 | 0.9039 | 0.8853 | **0.9497** | 0.9164 |
| | Co_tr ⑦ | 0.9017 | 0.8722 | **0.9337** | 0.9019 | **0.9334** | 0.8717 | 0.9015 |
| TWITTER | FG-DSEN | **0.9350** | 0.9650 | 0.9370 | **0.9508** | 0.8791 | 0.9309 | **0.9042** |
| | No ① | 0.8881 | **0.9976** | 0.8305 | 0.9091 | 0.7481 | **0.9959** | 0.8544 |
| | One tr ② | 0.9122 | 0.9608 | 0.9060 | 0.9326 | 0.8288 | 0.9248 | 0.8742 |
| | One tr ③ | 0.9109 | 0.9921 | 0.8740 | 0.9293 | 0.7938 | 0.9858 | 0.8794 |
| | One tr ④ | 0.9042 | 0.9820 | 0.8730 | 0.9243 | 0.7894 | 0.9675 | 0.8694 |
| | Two tr ⑤ | 0.9229 | 0.9692 | 0.9140 | 0.9408 | 0.8434 | 0.9411 | 0.8895 |
| | Co_tr ⑥ | 0.8934 | 0.9657 | 0.8720 | 0.9164 | 0.7827 | 0.9370 | 0.8529 |
| | Co_tr ⑦ | 0.8646 | 0.8537 | **0.9630** | 0.9051 | **0.8984** | 0.6646 | 0.7640 |
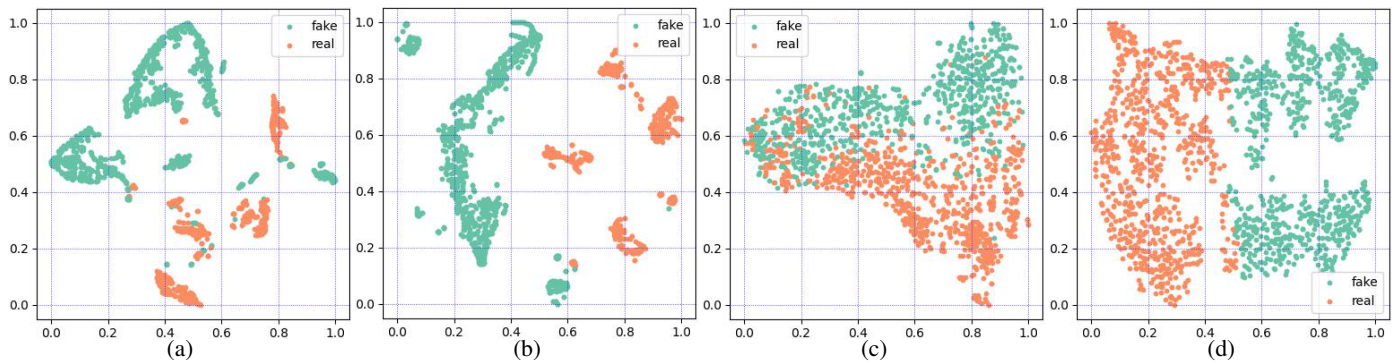


Fig. 3. (a) and (b) depict two features from the Twitter dataset, while (c) and (d) depict two features from the Weibo dataset. (a) and (c) represent features that have not undergone differences-similarities enhancement network processing, while figures (b) and (d) represent those that have.

sion as the stitching projection features.

Table V and Fig. 2 present the results of these ablation experiments.

The overall impact of the DS enhancement network is demonstrated by comparing the features before and after the network on the two datasets, see Fig. 3. We can find that after passing through the differences-similarities enhancement network, samples from each category are more closely clustered and exhibit distinct boundaries.

Based on Experiment ①, it is evident that the classification performance deteriorates in the absence of the DS enhancement network. Within the DS enhancement network, we compare experiments ②, ③, and ④ and find that only DS projection features work best on the Weibo dataset, and only stitching projection features work best on the Twitter dataset. This indicates that each of the two features is effective. However, directly connecting stitching projection features and DS projection features and inputting them into the self-attention module for enhancement proves to be ineffective. A

possible explanation is that the two features are not in the same semantic space and represent original and DS information. Excessive fusion can have a detrimental effect and contaminate the extracted features. Experiment ⑤ indicates a slight decrease in model performance due to a reduction in the number of parameters. However, the shared weight model was the most effective in the ablation experiments, except for the original model, and outperformed all other baseline models in the previous subsection in performance. From experiments ⑥, ⑦, we can see that two self-attention modules in parallel work much better than a single co-attention transformer, despite having the same number of parameters. Additionally, directly inputting text fine-grained features and image fine-grained features of the same dimension does not effectively capture DS information in news content and is not conducive to detecting fake news. These experiments validate the rationality of our designed DS enhancement network.

## V. Conclusion

This study proposes a fine-grained differences-similarities (DS) enhancement network for fake news detection. Initially, the model extracts fine-grained features from text and images using a modified pre-training model to minimize the loss of valid information in news posts. The DS enhancement network is then employed to enhance both the stitching features and DS features of the news, ensuring interaction between original modal information while highlighting DS information in news content to aid in fake news detection. The improvement achieved by using the DS enhancement network is more significant than that achieved by adding auxiliary tasks or extracting multi-level features. Experiments demonstrate that the FG-DSEN proposed in this paper outperforms state-of-the-art methods on two public and popular social media datasets.

This study has certain limitations, as it cannot be directly applied when one of the modalities is missing. In scenarios where news articles solely comprise of textual or visual content, models exhibit limited performance in handling such cases. Additionally, if manipulated images or artificially generated deceptive images are employed to align with fake news narratives, it is possible that the extraction of DS features could be compromised, leading to potential challenges in detecting fake news.

For future work, we aim to enhance the model's capabilities in the detection of fake news in scenarios where modalities are missing. This would enable the model to be more versatile in detecting both single-modal and multimodal fake news. Furthermore, we plan to augment the feature extraction process to address manipulated images or artificially generated deceptive images, incorporating them into the construction of DS features. This enhancement is expected to fortify the model's robustness and improve its overall performance.

## References

[1] C. G. Song, N. W. Ning, Y. L. Zhang, and B. Wu, "A multimodal fake news detection model based on crossmodal attention residual and multichannel convolutional neural networks," *Information Processing & Management*, vol. 58, no. 1, p. 14, 2021.

[2] H. Allcott and M. Gentzkow, "Social media and fake news in the 2016 election," *Journal of Economic Perspectives*, vol. 31, no. 2, pp. 211–236, 2017.

[3] Z. W. Jin, J. Cao, Y. D. Zhang, J. S. Zhou, and Q. Tian, "Novel visual and statistical image features for microblogs news verification," *Ieee Transactions on Multimedia*, vol. 19, no. 3, pp. 598–608, 2016.

[4] C. Raj and P. Meel, "Convnet frameworks for multi-modal fake news detection," *Applied Intelligence*, pp. 1–17, 2021.

[5] T. Rasool, W. H. Butt, A. Shaukat, and M. U. Akram, "Multi-label fake news detection using multi-layered supervised learning," in *Proceedings of the 2019 11th international conference on computer and automation engineering*, Conference Proceedings, pp. 73–77.

[6] T. Zhang, D. Wang, H. Chen, Z. Zeng, W. Guo, C. Miao, and L. Cui, "Bdann: Bert-based domain adaptation neural network for multi-modal fake news detection," in *2020 international joint conference on neural networks (IJCNN)*. IEEE, Conference Proceedings, pp. 1–8.

[7] P. Li, X. Sun, H. Yu, Y. Tian, F. Yao, and G. Xu, "Entity-oriented multi-modal alignment and fusion network for fake news detection," *IEEE Transactions on Multimedia*, vol. 24, pp. 3455–3468, 2021.

[8] J. Lu, D. Batra, D. Parikh, and S. Lee, "Vilbert: Pretraining task-agnostic visiolinguistic representations for vision-and-language tasks," in *Advances in neural information processing systems*, vol. 32, Conference Proceedings, pp. 13–23.

[9] A. Vaswani, N. Shazeer, N. Parmar, J. Uszkoreit, L. Jones, A. N. Gomez, Kaiser, and I. Polosukhin, "Attention is all you need," in *Advances in neural information processing systems*, vol. 30, Conference Proceedings, pp. 5998–6008.

[10] C. Castillo, M. Mendoza, and B. Poblete, "Information credibility on twitter," in *Proceedings of the 20th international conference on World wide web*, Conference Proceedings, pp. 675–684.

[11] V. Pérez-Rosas, B. Kleinberg, A. Lefevre, and R. Mihalcea, "Automatic detection of fake news," in *27th International Conference on Computational Linguistics*. Association for Computational Linguistics, 2019, Conference Proceedings, pp. 3391–3401.

[12] V. Sahana, A. R. Pias, R. Shastri, and S. Mandloi, "Automatic detection of rumoured tweets and finding its origin," in *2015 International Conference on Computing and Network Communications (CoCoNet)*. IEEE, Conference Proceedings, pp. 607–612.

[13] H. Ahmed, I. Traore, and S. Saad, "Detecting opinion spams and fake news using text classification," *Security & Privacy*, vol. 1, no. 1, p. e9, 2018.

[14] M. Alrubaian, M. Al-Qurishi, M. M. Hassan, and A. Alamri, "A credibility analysis system for assessing information on twitter," *IEEE Transactions on Dependable and Secure Computing*, vol. 15, no. 4, pp. 661–674, 2018.

[15] V. Indu and S. M. Thampi, "A nature-inspired approach based on forest fire model for modeling rumor propagation in social networks," *Journal of network computer applications*, vol. 125, pp. 28–41, 2019.

[16] R. K. Kaliyar, A. Goswami, P. Narang, and S. Sinha, "Fndnet–a deep convolutional neural network for fake news detection," *Cognitive Systems Research*, vol. 61, pp. 32–44, 2020.

[17] S. R. Sahoo and B. B. Gupta, "Multiple features based approach for automatic fake news detection on social networks using deep learning," *Applied Soft Computing*, vol. 100, p. 106983, 2021.

[18] H. Jwa, D. Oh, K. Park, J. M. Kang, and H. J. A. S. Lim, "exbake: Automatic fake news detection model based on bidirectional encoder representations from transformers (bert)," vol. 9, no. 19, p. 4062, 2019.

[19] J. D. M.-W. C. Kenton and L. K. Toutanova, "Bert: Pre-training of deep bidirectional transformers for language understanding," in *Proceedings of NAACL-HLT*, 2019, pp. 4171–4186.

[20] S. Singhal, R. R. Shah, T. Chakraborty, P. Kumaraguru, and S. Satoh, "Spotfake: A multi-modal framework for fake news detection," in *2019 IEEE fifth international conference on multimedia big data (BigMM)*. IEEE, Conference Proceedings, pp. 39–47.

[21] Y. Wang, F. Ma, Z. Jin, Y. Yuan, G. Xun, K. Jha, L. Su, and J. Gao, "Eann: Event adversarial neural networks for multi-modal fake news detection," in *Proceedings of the 24th acm sigkdd international conference on knowledge discovery & data mining*, Conference Proceedings, pp. 849–857.

[22] Z. Jin, J. Cao, H. Guo, Y. Zhang, and J. Luo, "Multimodal fusion with recurrent neural networks for rumor detection on microblogs," in *Proceedings of the 25th ACM international conference on Multimedia*, Conference Proceedings, pp. 795–816.

[23] Y. Wu, P. Zhan, Y. Zhang, L. Wang, and Z. Xu, "Multimodal fusion with co-attention networks for fake news detection," in *Findings of the Association for Computational Linguistics: ACL-IJCNLP*, Conference Proceedings, pp. 2560–2569.

[24] S. Qian, J. Wang, J. Hu, Q. Fang, and C. Xu, "Hierarchical multi-modal contextual attention network for fake news detection," in *Proceedings of the 44th International ACM SIGIR Conference on Research and Development in Information Retrieval*, Conference Proceedings, pp. 153–162.

[25] J. Jing, H. Wu, J. Sun, X. Fang, and H. Zhang, "Multimodal fake news detection via progressive fusion networks," *Information Processing & Management*, vol. 60, no. 1, p. 103120, 2023.

[26] K. Simonyan and A. Zisserman, "Very deep convolutional networks for large-scale image recognition," in *3rd International Conference on Learning Representations (ICLR 2015)*. Computational and Biological Learning Society, 2015, pp. 1–14.

[27] C. Boididou, K. Andreadou, S. Papadopoulos, D.-T. Dang-Nguyen, G. Boato, M. Riegler, and Y. Kompatsiaris, "Verifying multimedia use at mediaeval 2015," in *MediaEval 2015 Workshop*, vol. 3, Conference Proceedings, p. 7.

[28] D. Khattar, J. S. Goud, M. Gupta, and V. Varma, "Mvae: Multimodal variational autoencoder for fake news detection," in *The World Wide Web Conference*, Conference Proceedings, pp. 2915–2921.

[29] S. Singhal, A. Kabra, M. Sharma, R. R. Shah, T. Chakraborty, and P. Kumaraguru, "Spotfake+: A multimodal framework for fake news detection via transfer learning (student abstract)," in *Proceedings of the AAAI conference on artificial intelligence*, vol. 34, Conference Proceedings, pp. 13 915–13 916.

[30] X. Zhou, J. Wu, and R. Zafarani, "Safe: Similarity-aware multi-modal fake news detection," in *Pacific-Asia Conference on knowledge discovery and data mining*. Springer, 2020, pp. 354–367.

# Detecting and Unmasking AI-Generated Texts through Explainable Artificial Intelligence using Stylistic Features

Aditya Shah*, Prateek Ranka†, Urmi Dedhia‡, Shruti Prasad§, Siddhi Muni¶ and Kiran Bhowmick‖
Department of Computer Engineering, Dwarkadas J. College of Engineering
Mumbai, India

*Abstract*—In recent years, Artificial Intelligence (AI) has significantly transformed various aspects of human activities, including text composition. The advancements in AI technology have enabled computers to generate text that closely mimics human writing which is raising concerns about misinformation, identity theft, and security vulnerabilities. To address these challenges, understanding the underlying patterns of AI-generated text is essential. This research focuses on uncovering these patterns to establish ethical guidelines for distinguishing between AI-generated and human-generated text. This research contributes to the ongoing discourse on AI-generated content by elucidating methodologies for distinguishing between human and machine-generated text. The research delves into parameters such as syllable count, word length, sentence structure, functional word usage, and punctuation ratios to detect AI-generated text. Furthermore, the research integrates Explainable AI (xAI) techniques—LIME and SHAP—to enhance the interpretability of machine learning model predictions. The model demonstrated excellent efficacy, showing an accuracy of 93%.Leveraging xAI techniques, further uncovering that pivotal attributes such as Herdan's C, MaaS, and Simpson's Index played a dominant role in the classification process.

*Keywords*—*Detecting AI generated text; computer generated text; AI generated text; text classification; machine learning; pattern recognition; Stylistic features; Explainable AI; Lime; Shap*

## I. INTRODUCTION

Artificial Intelligence (AI) has had a significant impact on how humans perform daily tasks [1], such as composing text, in recent years. The technology behind it has improved to the point that computers are now capable of generating text that closely resembles human writing. This has resulted in issues such as circulating false information and stealing identities. It's also made things less apparent, which could be dangerous for security. Given the importance of these dangers and issues [2], it is critical that the underlying patterns used by various text generation techniques are uncovered. The research paper sets ethical guidelines for emulating human styles or perspectives by distinguishing AI-generated writing from human-generated language or examining the patterns formed by AI.

Researchers have tried several methods to understand how AI generates material. Curvature-based hypothesis and perturbation discrepancy detection of machine-generated text. The hypothesis argues that machine-generated text will be at the negative curvature and human-generated text will be at the positive curvature.If the perturbation discrepancy is more than 0, the text is machine-generated; if it goes to 0, it is human-generated [3].

As input, many textual properties such as length, punctuation, and word choice are utilized. On five models, an ensemble technique with Logistic Regression is used for binary classification (text is either human or machine-generated). Three models are utilized directly without cross-validation for multiclass classification (to determine which deep neural model was used for text synthesis) [4].

The primary focus for detecting AI-generated text is linguistic analysis [5], which breaks out syntactic patterns, word choices, and sentence structures. When a person uses too many words, repeats the same thing, or breaks the rules, this is a red signal. Investigating AI prompts and replies that don't match is crucial. If the AI model doesn't make sense or changes style, a machine may be implicated. Metadata is another option. AI creation may be indicated by unusual timestamps or IP addresses. Anomaly detection methods point out when language patterns are broken. Machine learning models trained to spot anomalies can distinguish AI writing from human-written language. Determining if writing was created by AI is complicated and ever-changing. Linguistic signals, inconsistency analysis, information inspection, stylometric quirks, bias identification, outliers, and purpose-built models are crucial.

Detecting AI-generated text remains an evolving effort, with several uncharted areas that demand attention for more robust and accurate identification. Firstly, there's a need to collect a diverse and thorough corpus of training data, spanning various AI models, linguistic styles, and genres, to ensure the detection system's adaptability. Fine-tuning detection models for specific AI language generators could improve precision by honing in on the unique attributes of each model. Contextual understanding remains a problem, as AI-generated text often lacks coherence. Developing methods that examine contextual disparities and irregularities could support the detection of AI-generated text. The rise of multimodal AI-generated content demands the development of detection models that can study and correlate text, images, and videos, expanding the scope of accurate identification. To counter evolving AI models, adversarial approaches must be adaptive, having a constant back-and-forth development between detection and generation. Ensuring real-time detection capabilities is crucial, especially for online platforms, necessitating the creation of lightweight, quick-response systems that analyze text as it's created.

This research paper aims to explore various methods for

identifying AI-generated text. The paper discusses various factors that need to be considered while detecting AI-generated text. These include parameters such as average syllable count, average word length, average sentence length by word, count of functional words, punctuation count ratio, and many more. Further, it implements xAI techniques which are LIME and SHAP to assist in interpreting and comprehending the predictions provided by the machine learning models.It contributes to the continuing discussion concerning AI-generated material by throwing light on the methodologies and approaches used to distinguish between human and machine-generated text.

Section II covers a wide range of techniques for detecting and understanding AI-generated text. The section provides insights into various approaches used to differentiate between machine and human-generated content, underscoring the evolving nature of this research. Section III provides a comprehensive overview of the technologies employed in this research and Section IV discusses the proposed model. In Section V, experimentation done using fine-tuning of hyperparameters is discussed and Section VI discusses the results with the conclusion in Section VII followed by future scope in Section VIII.

## II. Review of Literature

Various features extracted from the text, such as length, punctuation, and word choice, are used as input. For binary classification (text is whether human or machine generated), an ensemble technique with Logistic Regression is applied to five models().For multiclass classification (to determine which deep neural model was used for text generation), three models are used directly without cross-validation [4].

The paper explores various detection methods, including classifiers trained from scratch, zero-shot classifiers utilizing pre-trained TGMs, and fine-tuning pre-trained languages models like RoBERTa and GROVER. While the RoBERTa detector shows promising results, it requires a substantial number of training examples, making it less practical (). The paper highlights the difficulties faced by the state-of-the-art RoBERTa detector, including identifying short and fluent MGT instances, factual errors, spurious entities, contradictions, and violations of common sense reasoning [6].

In the context of text recognition using the GLTR model, the underlying assumption of their methods is to generate natural-looking text. Most systems sample from the head of the distribution through max sampling, k-max sampling, beam search,temperature-modulated sampling, or even implicitly with rule-based templated approaches. [7].

A curvature-based criterion that makes use of hypothesis and perturbation discrepancy to detect machine-generated text. The hypothesis states that if the text is machine-generated, then it will lie at the negative curvature and if it is human-generated, then it will occupy the positive curvature. If the perturbation discrepancy is greater than 0, it implies that the text is machine-generated and if the perturbation discrepancy tends to 0, it implies that the text is human-generated [3].

The author in [8] explores various approaches such as Multimodal Explanation, Deep Visual Explanation, and Deep Tensor Networks to create models that can provide explanations for their decisions using visual and textual modalities. In the context of understanding and interpreting AI models and their decisions, the paper emphasizes the crucial role of xAI. It emphasizes the need for AI systems to provide explanations for their decisions in sensitive areas like healthcare. It also presents different approaches for the explainability of AI models. The paper concludes by discussing the importance of xAI.

Researchers collected a dataset of 500 data points by gathering responses from computer science students for essay and programming assignments [9]. Each response was labeled as either Human-written or machine-generated. To analyze the text, they used a technique called Term Frequency-Inverse Document Frequency (TF-IDF) for feature extraction, which converts the text into numerical representations that machine learning models can understand.

The researchers created an open dataset for the Russian language consisting of long texts generated by different models with varying parameters and sampling methods, balanced with human-written text, and experiments with data mixing which shows that blending samples from different generative models improved the generalization ability of the detector models particularly helping RoBERTa-based models in detecting machine-generated text [10]. They further increased the input length sequence which then improved the model's understanding of the context and led to better detection performance and Multi-Task learning where the model simultaneously trains on multiple tasks, proved beneficial for improving the quality of the discriminator.

This research work focused on improving the stability of the LIME algorithm in xAI. LIME (Local Interpretable Model-Agnostic Explanations) is used to explain AI algorithms [11]. The researchers identified two main stability issues with LIME which are Segment Ordering and Region Flipping and to improve LIME's stability, they proposed two strategies: High Sample size and Average Segment Weights.

The paper [12] provides a guided tutorial of the xAI implementation in the field of Software Engineering. It provides an introduction to xAI. Further, it provides fundamental knowledge of defect prediction models. It addresses three successful case studies where xAI is used in defect prediction models.

The authors explore challenges in distinguishing Large Language Models (LLMs) and human-generated text. They derive complexity bound for detecting AI-generated text, indicating a number of samples needed for detection [13]. The researchers also discuss different existing approaches for detecting AI-generated text, highlighting the ethical concerns related to the misuse of LLMs.

In the study [14], various methods for detecting AI-generated text are explored. There are several techniques that include analyzing word pair frequency, linguistic characteristics, lexicographical features, and many more. The paper provides details on the methodology and results of each method. Further, it concludes that there is no single best method, and further evaluation of standardized datasets is necessary.

In the research, three decoding strategies are examined. They show that the improvement in these methods is for fooling humans, rather than difficult detectable text. These decoding strategies include top-k and untruncated random

sampling [15]. The authors emphasize the importance of using both human and automatic detection methods to assess the humanness of text generation systems. They call for further research in improving language models, building better automatic detectors, and developing tools to improve human detection of machine-generated text.

The research proposes a classification model for detecting essays generated by ChatGPT [16]. The model is based on XGBoost. It is trained and further evaluated on a dataset generated by ChatGPT and written by humans. It also explores feature engineering for better results. It specifically explores TF-IDF and other hand-crafted features.

The research examines various Machine Translation methods and assesses the linguistic complexity of their translations in terms of both vocabulary and grammar [17]. The study uses different metrics to measure diversity, such as lexical richness and morphological variety and applies these metrics to translations produced by MT models.

This study evaluates 13 lexical diversity metrics for tracking the progression of French learners' written productions. [18]They used a semi-longitudinal corpus of learners' essays and applied random forests to predict the production wave. The metrics show varying correlations and the ability to detect differences between productions achieving 69% accuracy in predicting production waves

The study presents a variety of techniques, including linguistic analysis, frequency counting, perplexity-based filtering, and more. [14]These methods leverage different aspects of the text, such as syntactic patterns, linguistic features, and statistical properties, to differentiate between human-written and machine-generated content.

In order to analyze complex machine learning models, the study introduces a unifying framework termed SHAP. The framework determines the significance of each feature in a model for a certain prediction [19]. The framework introduces new ways and unites six current methods to enhance computational efficiency and compatibility with human intuition. To illustrate how well SHAP works at understanding model predictions, the paper includes theoretical findings, computational experiments, and user studies.

The authors of this scientific study suggest a categorization method for categorising research paper abstracts using several machine-learning approaches. The goal is to automatically classify the papers into three categories: business, social science, and science [20]. Four machine learning techniques are tested by the authors: Support Vector Machines (SVM), Naive Bayes, K-Nearest Neighbour (KNN), and Decision Tree. Tokenization, stemming, and stop word removal are used in the pre-processing of the abstracts. For feature extraction, Bag of Words and TF-IDF vectorization techniques are applied. The authors contend that the algorithm could function even better with more data. Overall, the study shows that machine learning approaches may successfully categorize research articles based on their abstracts.

The article proposes a GPT language model and investigates its Python code-writing capabilities [21]. In contrast to GPT-3's performance of 0% and GPT-J's performance of

11.4%, the researchers are able to provide better results. Furthermore, they find that frequent sampling from the model is an extremely effective technique for coming up with workable solutions to difficult problems. The model has a number of faults, including problems with binding operations to variables and docstrings that provide detailed information. Finally, the paper goes over the wider effects that utilizing strong code generation methods might have on safety, security, and economics.

In summary, the literature survey illuminates the complexities and multifaceted nature of AI-generated text analysis, revealing that advancements in the field are often accompanied by intricate challenges and unexplored areas. This research paper endeavors to offer a comprehensive solution to the intricate challenge of detecting text that originates from artificial intelligence (AI) systems.

## III. OVERVIEW OF TECHNOLOGIES USED

Technologies used in this research can be broadly classified into three groups:

### A. Machine Learning Algorithms

For AI-generated text detection, various machine learning models were chosen such as Decision Tree, Random Forest, Logistic Regression, and Support Vector Machine (SVM), Gradient Boosting. These models were chosen with the specific intention of utilizing xAI.

The selection of these models for xAI was driven by several key considerations such as:

1) Interpretability: For eg, Decision Trees provide a clear and intuitive decision-making structure represented by tree-like diagrams making it easier to understand. Interpretable coefficients provided by models like Logistic Regression and SVM indicate the impact of each feature on the outcome.

2) Balancing complexity: These models strike a balance between performance and complexity. While more complex models like neural networks may help in achieving higher accuracy, they are difficult to interpret. The chosen models provide a reasonable trade-off between predictive power and interpretability.

(A) Logistic Regression [22]: It is a statistical method used for binary classification tasks by making use of the logistic function also known as sigmoid function, which transforms a linear combination of predictor variables into a value between 0 and 1. The logistic regression is expressed by:

$$P(Y=1|X) = \frac{1}{1+e^{-(\beta_0+\beta_1 X_1+\beta_2 X_2+...+\beta_p X_p)}} \tag{1}$$

(B) Decision Tree [23]: It employees the Gini index to make informed decisions during the process of creating a tree like structure for classification tasks. It uses a recursive process to partition the feature space into regions to minimise impurity and improve classification accuracy. The Gini index is a measure of impurity and

its formula is given by:

$$Gini(t) = 1 - \sum_{i=1}^{C} (p(i|t))^2 \qquad (2)$$

(C) Gradient Boosting [24]: It is an advanced machine learning method that builds a strong predictive model by combining multiple weak learners. It makes use of Gradient Descent optimization to minimise the predictive errors.

$$F(x) = \sum_{m=1}^{M} \gamma \times f_m(x_i) \qquad (3)$$

(D) Support Vector Machines (SVM) [25]: It is a powerful classification technique that aims to find a hyperplane in a high-dimensional feature space that best separates different classes of data points. The main idea behind SVM is to maximise the margin between the classes, which is the distance between the hyperplane and the nearest data points of each class.

$$h(x) = sign(\sum_{i=1}^{n_{SV}} a_i y_i \times K(x_1 x_i) + b) \qquad (4)$$

(E) Random Forest [26]: It is an ensemble learning method that combines multiple decision trees to improve the classification accuracy. It uses random subsets of data and features to build diverse trees , thus making independent predictions.

$$\hat{y} = \frac{1}{N} \sum_{i=1}^{N} f_i(x) \qquad (5)$$

*B. xAI Libraries*

xAI for classification refers to the application of techniques that provide transparent and interpretable explanations for the predictions made by classification models. It also refers to the concepts and techniques used to make artificial intelligence models more transparent and interpretable to humans. In classification tasks, where the model assigns input data to specific categories or classes, xAI techniques focus on revealing the contributing factors that led to a particular classification outcome. Commonly used techniques and models include LIME, feature importance, PDP(Partial Dependency Plots), and SHAP.

1) LIME - It is a technique designed to explain the predictions made by complex ML models, particularly "black-box" models, in a more understandable and interpretable way. LIME helps bridge the gap between the often opaque nature of advanced ML algorithms and the need for human-understandable explanations.

2) SHAP - SHAP, which stands for "SHapley Additive exPlanations," is a powerful technique used in machine learning to explain the predictions of various models. It provides a unified framework for explaining the output of any machine learning model by assigning "importance" values to each feature in a prediction. SHAP values are based on cooperative game theory and offer a comprehensive understanding of feature contributions to individual predictions.

*C. Stylistic features*

TABLE I. STYLISTIC FEATURES AND VARIOUS SCORES CALCULATED FOR THE DATA POINTS

| Linguistic Features | Scores | Description |
|---|---|---|
| Lexical Features | Average Word Length [27] | This gives us the average word length of the concerned text in terms of the number of characters used. |
| | Average Sentence Length By Word [28] | This gives us the average number of syllables used per word in the concerned text. |
| | Functional Words Count [29] | Functional words are grammatical connectors or mood-defining words within phrases, lacking significant linguistic value on their own. |
| | Punctuation Count | This gives us the ratio of the number of punctuations used to the number of characters used in the concerned text. |
| Readability Score | Flesch Reading Ease [30] | This metric assesses a text's readability by analyzing its ease of comprehension. Score Range: The scores range from 0 to 100. Text with a higher score is more likely to be easier to read. |
| | Flesch-Kincaid Grade Level [31] | This metric estimates the U.S. school grade level required to grasp the material. Score Range: Scores can be any value greater than zero. Lower scores suggest that comprehension is possible at lower grade levels. |
| | Gunning Fog Index [32] | The Gunning Fog Index determines how many years of official schooling are required for a person to fully understand a text. Score Range: The scores range from 0 to 20. Lower scores indicate simpler text. |
| | Dale-Chall Readability Formula [33] | Dale-Chall The readability formula considers a set of well-known words and uses their presence to determine the readability of the text. Score Range: Approximately similar to US grade levels. Lower scores imply that the text is easier to read. |

The research uses various stylistic features which are calculated for every text in the data set. These features include lexical features, readability, and diversity and richness of vocabulary. These features are important and used further in the research for model training and to discover patterns and information regarding the text that are not visible and perceptible to the human eye. Table I and Table II explain the various features that are noted and calculated for the texts present in the data set.

IV. PROPOSED METHODOLOGY

The proposed methodology for this research consists of two major pipelines:

1) Dataset Generation Pipeline
2) Model Training and xAI Pipeline

All the steps occurring in both pipelines are explained in detail below.

*A. Dataset generation pipeline*

Fig. 1 represents the flow for the creation of the two datasets used in this research.

1) Prompt generation for every data point: The proposed model's datasets are constructed using introductions from Wikipedia articles, specifically human-generated texts.

TABLE II. Stylistic features and various scores calculated for the data points (Diversity and Richness of Vocabulary)

| Linguistic Features | Scores | Description |
|---|---|---|
| Diversity and Richness of Vocabulary | Yule's Characteristic K [34] | Yule's Characteristic K measures text "disorderliness" by analyzing word frequency distribution, calculating the ratio of total words to the square root of its inverse. A lower value indicates greater vocabulary diversity, while a higher value suggests more word repetition and lower vocabulary richness. |
| | Herdan's C [35] | Herdan's C quantifies word frequency distribution in a text by subtracting the logarithm of total words from the logarithm of unique words. It offers insights into the text's vocabulary distribution. |
| | Maas [36] | Maas is a measure derived using a formula by Mueller involving variables like "logeV0," representing vocabulary expansion, where natural logarithm is employed, and incorporating variables a, logV0, and V to indicate proportional vocabulary expansion across the text. |
| | Mean segmental TTR(Type Token Ratio) (MSTTR) [37] | Mean Segmental TTR (MSTTR) calculates the average Type-Token Ratio (TTR) over consecutive text segments, where TTR is the ratio of unique words to total words in a segment. It detects shifts in vocabulary diversity within the text. |
| | Simpson's Index [38] | Measure that quantifies the likelihood of two words randomly selected from a text being identical. The scale spans from 0, representing a state of high diversity, to 1, indicating a state of low diversity. |
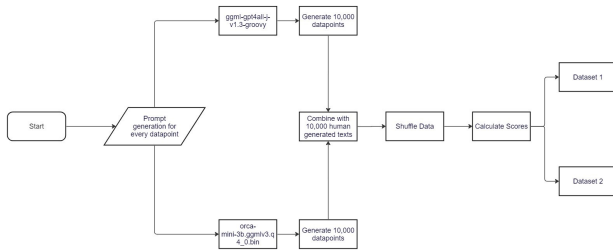


Fig. 1. Dataset creation pipeline

The creation process involves employing a prompt in the format "200-word Wikipedia-style introduction on 'title' starter_text." Here, 'title' represents the Wikipedia page title, and 'starter_text' comprises the first seven words from the introduction paragraph of the respective article.

2) LLMs used to generate text: Two large language models, namely "ggml-gpt4all-j-v1.3-groovy" [39]and "orca-mini-3b.ggmlv3.q4_0.bin" [39], are utilized to generate a set of 10,000 data points for each model. These data points are then combined with the human-generated text, resulting in two separate datasets, each containing 20,000 data points. The final datasets are created by shuffling the data points independently for each of the models along with the human-generated text.

3) AI text generation: Both LLMs then produce 10000 AI-generated texts each for a better variety and spread of data.

4) Combining the data: All the AI-generated texts from both LLMs are then combined with 10,000 human-generated texts individually from the two LLMs.

5) Shuffling data: All of these data points are then shuffled so that the machine learning models used ahead do not learn

any unintended patterns from the data, thereby impeding the performance of the model. This step denotes the creation of an intermediate datasets for this research.

6) Calculating Scores & Final Datasets: Every data point in the intermediate datasets, undergoes a series of calculations that help determine various style characteristics and linguistic features of the text such as readability, richness and correctness of vocabulary, and semantic spread of the text, and lexical features that are not lucid and discernible to the human eye. Each of these characteristics has been attributed to various scores that help determine such features in the text. These scores are then appended to the intermediate dataset thus completing the dataset generation process and thereby creating two datasets for the LLMs used.
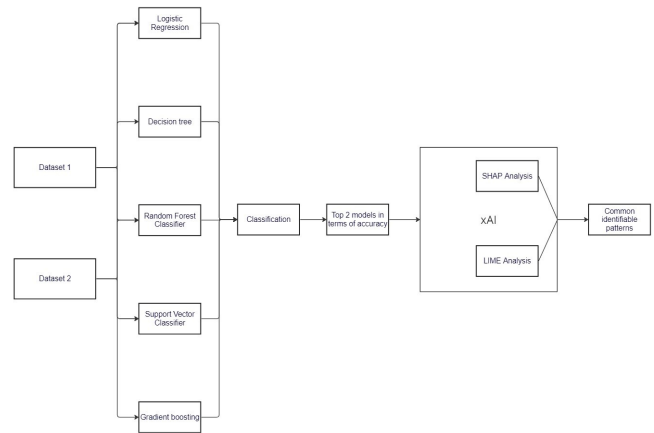


Fig. 2. Model Training and xAI pipeline

Following is the brief of all the scores used to extract the stylistic features later on in this research.

(A) Lexical Features: One of the ways in which AI generated text and human text can be distinctly identified is by its lexical structure. Usually, human text is erroneous in terms of appropriate punctuation - punctuation marks are fairly missed or used improperly. Similarly, there are disparities in other areas of lexical architectures such as the differences in word lengths and thus the number of syllables (AI tends to use heavier words), differences in typical sentence lengths, the varied usage of functional words such as she, these, or, and, etc. and so on. Hence, these factors are calculated for both classes of texts and used in this research paper to identify the trends for the same.

(B) Readability Scores: Readability scores seek to identify the reading level of a particular text, usually in terms of the minimum education level required to read the text with ease. Since human texts and AI texts are bound to differ in terms of readability ease, this paper made use of the following readability metric formulae to quantitatively identify the reading ease of human and AI generated text both:

a) Flesch Reading Ease:

$$206.835 - 1.015(\frac{totalwords}{totalsentences}) - 84.6(\frac{totalsyllables}{totalwords})$$
(6)

b) Flesch-Kincaid Grade Level:

$$0.39(\frac{totalwords}{totalsentences}) + 11.8(\frac{totalsyllables}{totalwords}) - 15.59$$
(7)

c) Gunning Fog Index:

$$0.4 \cdot [(\frac{totalwords}{totalsentences}) + 100(\frac{complexwords}{totalwords})]$$ (8)

d) Dale-Chall Readability Formula: The Dale-Chall Formula compares its wordlist to the provided text and then determines the U.S. grade level based on the number of difficult words and average sentence length.

(C) Diversity and richness of the vocabulary: The vocabulary used by AI to generate texts and that used by human writers is vastly different. Human text considers several other factors apart from the meaning and semantics while selecting a word, such as cultural relevance, formal/informal style, text's context and usage, etc. AI on the other hand tends to focus more on the textbook definition rather than these factors, thus causing a disparity with human text even between sentences meant to convey the same meaning. The following vocabulary richness and diversity metric formulae were used in determining the vocabulary levels for both the classes of texts:

a) Yule's Characteristic K:

$$K = \frac{10^4}{N^2} \sum_{i=1}^{V} (n_i - c)^2$$
(9)

Where,
N is the total number of words in the text.
V is the vocabulary size (the number of distinct terms/words).
$n_i$ is the frequency of the ith word.
c is the mean frequency of all words.

b) Herdan's C:
$$C = \frac{\log(V)}{\log(N)}$$
(10)

Where:
V is the vocabulary size (the number of distinct terms/words).
N is the total number of words in the text.

c) Maas:
$$a^2 = \frac{\log(N) - \log(V)}{\log(N^2)}$$
(11)

$$\log V_0 = \frac{\log V}{\sqrt{1 - \frac{\log V^2}{\log N}}}$$
(12)

The term "logeV0" is equivalent to 'logV0", but it should be noted that the natural logarithm (with base $e$) is employed for the logarithmic computations. Furthermore, the computations incorporate the variables $a$, $\log(V_0)$ (which exhibit dissimilarity from their prior values), and $V'$, which function as indicators of the proportional expansion of vocabulary across the text.

d) Mean segmental TTR(Type Token Ratio) (MSTTR):

$$\text{Mean Segmental TTR} = \frac{\text{Total TTR in all segments}}{\text{Number of segments}}$$

e) Moving Average TTR(Type Token Ratio) (MATTR): The formula remains the same as for MSTTR, however MATTR computes the average Type-Token Ratio (TTR) by considering a sliding window of words instead of mutually exclusive segments as in MSTTR.

f) Simpson's Index:

$$D = 1 - \sum_{i=1}^{V} (\frac{n_i}{N})^2$$
(13)

Where:
V is the vocabulary size (the number of distinct terms/words).
$n_i$ is the frequency of the ith word.
N is the total number of words in the text

### B. Model Training and xAI Pipeline

Fig. 2 demonstrates the classification and xAI pipeline as a whole which includes training of the datasets on various machine learning models and then using xAI libraries like LIME and SHAP to get various insights regarding the data points.

1) Machine Learning and Classification: Both generated datasets are trained on classification models such as Logistic Regression, Decision Tree Classifier, Random Forest, Support Vector Machines, and Gradient Boosting. This is done to see which model will perform better on these data sets. The classification task is whether a given text is AI-generated or human-generated.

2) Top Model Selection: The best two of the five models trained before are chosen for xAI analysis using LIME and SHAP as these models will provide better insights than the others. The top two models are selected on the basis of classification metrics such as accuracy,f1-score, precision, and recall.

3) xAI Analysis: Arbitrary data points of AI-generated are chosen and LIME and SHAP analysis is implemented. Model weights of the two best machine learning algorithms are used. The same is done for human-generated text as well. How LIME and SHAP were used in this research is discussed later.

4) Identifying Common Patterns: Upon conducting these xAI techniques, the ensuing analysis reports offer a wealth of insights. These insights are subsequently juxtaposed, whereupon commonalities amongst the patterns identified by various models are isolated. This convergence of identified features in both AI and human-generated text serves as a critical juncture, underpinning the suggestion of a preferred technique for discerning between AI-generated and human-generated text.

### C. xAI

*1) LIME(Local Interpretable Model-agnostic Explanations):* LIME is effectively implemented to interpret models used to classify between AI-generated and human-generated text in a dataset. In this scenario, the goal is to understand

how the model distinguishes between texts created by artificial intelligence systems and those written by humans. LIME can provide insights into which features or patterns the model relies on for making such distinctions.

In this research, LIME is implemented on various test data points to check which features were chosen by a particular model for classification. To implement LIME, a subset of data points is chosen randomly, comprising both AI-generated and human-generated text samples. Then LIME is used to identify the prevailing scores and metrics, and subsequently patterns congruous to AI as well as human-generated texts are studied and determined. These patterns are discussed later in this research.

*2) SHAP (SHapley Additive exPlanations):* SHAP is a powerful method that, like LIME, is used to interpret classification models for human-generated and AI-generated text. It helps in figuring out which parts of the text or words are most important to model's prediction of whether a piece of text was written by a person or an AI system i.e. it can be used to reveal the important factors influencing the model's conclusions when classifying AI-generated and human-generated text.

To use SHAP, a similar method of choosing a subset of data points is used that includes both types of text examples. SHAP then generates perturbed versions of these data points, similar to what LIME does. But instead of fitting a separate model that can be understood, SHAP uses an idea from cooperative game theory called Shapley values. These numbers tell how much each feature contributes to the prediction for a certain instance. The following are some SHAP visualization techniques that are

TABLE III. Hyperparameters tuned for Orca and GPT-J dataset

| Models | Hyperparameters tuned and tuned values for Orca dataset | Hyperparameters tuned and tuned values for GPT-J dataset |
|---|---|---|
| Logistic Regression | 'C' (Regularisation Strength):90.68 | 'C' (Regularisation Strength): 33.27 |
| Random Forest | n_estimators': 212, 'max_depth': 30,'min_samples_leaf': 2, 'min_samples_split': 4, 'bootstrap': False | n_estimators': 761, 'max_depth': 35, 'min_samples_leaf': 8, 'min_samples_split': 4, 'bootstrap': False |
| Gradient Boosting | 'n_estimators': 351, 'learning_rate': 0.18896, 'max_depth': 5, 'min_samples_leaf':8, 'min_samples_split': 8 | 'n_estimators': 486, 'learning_rate': 0.20436, 'max_depth': 9, 'min_samples_leaf': 7, 'min_samples_split': 3 |
| SVM | 'C' (Regularization Parameter): 9.05764, 'kernel': 'linear', 'degree': 2, 'gamma': 0.01 | 'C'(Regularization Parameter): 5.185706911647028, 'kernel': 'rbf', 'degree': 3, 'gamma': 0.1 |

used in this research to analyze the importance of individual features in the model's decision process:

1) Summary Plots: These graphs show how important each trait is across the whole dataset. They show the Shapley values for each feature, which show how they make the model's prediction move away from the average (base) estimate.
2) Waterfall Plots: Waterfall plots show how the Shapley value of each feature adds to the final prediction for a single instance. It makes it easier to see how the contributions add up.
3) Force Plots: Force plots are made to show how predictions can be made for specific cases. They show how the value

of each attribute and its Shapley value interact to affect the final prediction.

## V. Experimentation

### A. Parameter tuning

All the models were subjected to hyperparameter tuning to optimize the performance of various machine-learning models for AI-generated text detection. The process involved systematically searching and evaluating different combinations of hyperparameters to give the best set of hyperparameters that maximized the model's accuracy. For each model, a range of hyperparameter values was specified and RandomizedSearchCV was used which effectively sampled and cross-validated these values. This meticulous process enabled the models to better capture the patterns, resulting in improved accuracy and predictive capabilities. Table III shows the various hyperparameters used and their respective "best" values for model training to boost the accuracy of the models.

TABLE IV. Classification metrics for Orca generated dataset

| Model Name | Accuracy | F1-Score | Precision | Recall |
|---|---|---|---|---|
| **Logistic Regression** | **0.92** | **0.92** | **0.93** | **0.93** |
| Decision Tree | 0.80 | 0.79 | 0.80 | 0.77 |
| **Support Vector Classifier** | **0.91** | **0.92** | **0.93** | **0.92** |
| Random Forest | 0.86 | 0.86 | 0.84 | 0.89 |
| Gradient Boosting | 0.89 | 0.89 | 0.88 | 0.90 |

TABLE V. Classification metrics for GPT-J generated dataset

| Model Name | Accuracy | F1-Score | Precision | Recall |
|---|---|---|---|---|
| Logistic Regression | 0.67 | 0.68 | 0.65 | 0.66 |
| **Decision Tree** | **0.78** | **0.76** | **0.75** | **0.76** |
| **Support Vector Classifier** | **0.71** | **0.71** | **0.69** | **0.70** |
| Random Forest | 0.70 | 0.69 | 0.70 | 0.71 |
| Gradient Boosting | 0.65 | 0.65 | 0.64 | 0.61 |

From the above models, an ensemble model was created combining the predictions of various models using a weighted average based on their accuracy scores. The weights were determined by normalizing the accuracy scores, ensuring their sum equals 1.

## VI. Results and Discussion

### A. Classification Results

Both the datasets, the ones generated by GPT-J and Orca were trained on the various classification models mentioned above — Logistic Regression, Decision Tree, Random Forest, Support Vector Classifier, and Gradient Boosting. Both datasets had varied accuracies for the models trained. The various classification metrics such as accuracy, F1-Score, precision, and recall [40] for both datasets are illustrated in Table IV and Table V.

### B. xAI Results and Inferences

xAI was then implemented to determine which features are dominating and have a higher impact in determining the class label of a particular data point.
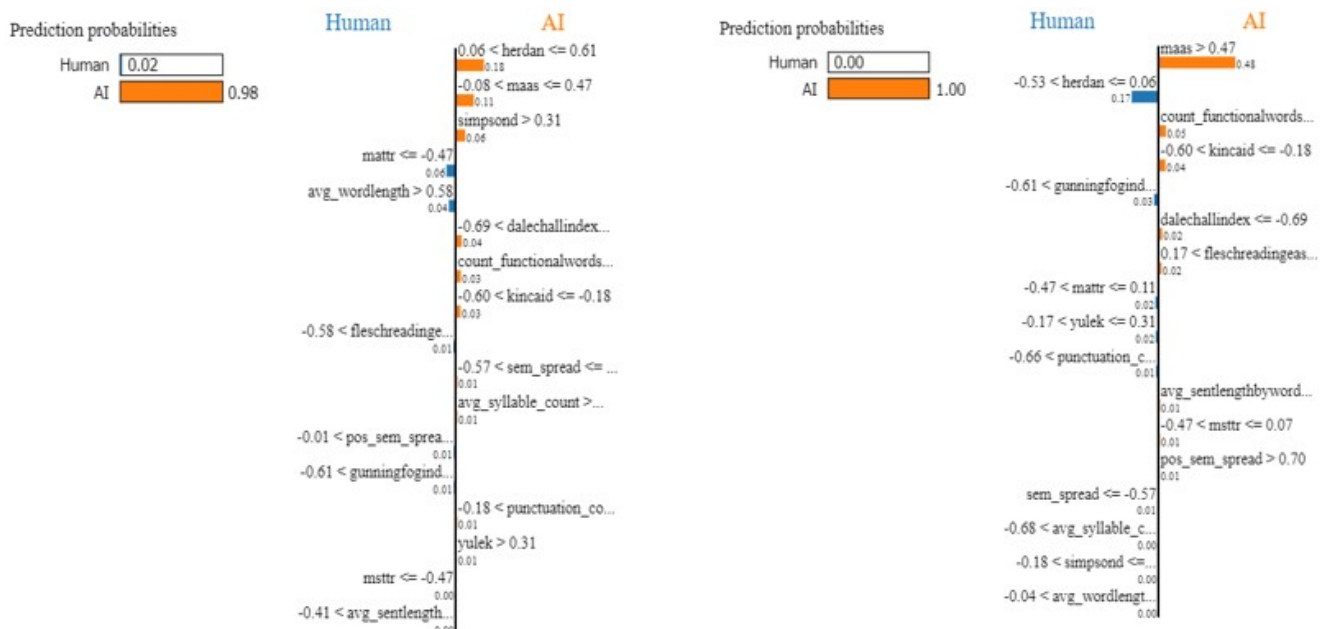
Fig. 3. LIME Interpretability Graphs for arbitrary AI-generated texts

LIME was then implemented on the Orca-generated dataset as it yielded better results to determine which features played an important role in how the model classified a data point as either human-generated or AI-generated text. This feature importance identification then helps in identifying what kinds of lexical and other features related to text are prominent in AI-generated and human-generated text.

The Fig. 3 has two LIME graphs for two separate AI-generated text data points. In the first image— on the left— LIME has Herdan's C [35], MaaS [36], and Simpson's index [38] have an abundant positive effect on the classification of this data point as an AI-generated text whereas MATTR and the average_word_length feature has a negative impact on the classification. From looking at various LIME graphs for data points being classified as AI generated the most dominant features were Herdans C, MaaS, and the Simpson's Index.

Herdan's C was one of the features which highly impacted the classification. Herdan's C metric is used to determine a text's vocabulary richness and diversity. It computes the proportion of unique words relative to the total number of words in the text. A higher Herdan's C value indicates a more diverse vocabulary, whereas a lower value indicates a repetitious or restricted vocabulary. It was observed from a sample of AI-generated data points that most of AI-generated text has a high value of this metric, meaning having a rich diversity of vocabulary was present. This is because the language model used to generate the data was pre-trained on massive datasets containing a wide range of text sources(3 billion parameters for Orca). But, there might be cases where the richness is abated because the dataset on which that language model was trained must not be up to standards.

The Simpson's Index can be used to measure the diversity of words in a given text within the context of text analysis. A higher Simpson's Index value would indicate less word diversity, indicating that a small number of words are repeated frequently. A lesser Simpson's Index value indicates greater word diversity or the use of a greater variety of words. Furthermore, for Simpson's Index, the values were high i.e. they were between 0.65 to almost reaching 1. This indicates that the phrases or words in the text are repeated often. Consequently, the diversity decreases. This is because AI models, particularly language models, can occasionally generate text that tends to reuse certain phrases or patterns, resulting in a relatively smaller vocabulary. These models may generate coherent text, but they may lack the inherent variability and creativity of human-generated text [41]. However, it's important to note that this can vary based on the specific AI model, the input data it was trained on, and the prompt given for text generation [42].

Fig. 4 illustrates a set of examples of LIME interpretability graphs for human-generated text. Many data points were interpreted and the results were mostly opposite to the ones inferred by the AI-generated ones. For instance, the Herdans C constant was relatively low for various human-generated text data points. It was either relatively low or it negatively influenced the classification.

Fig. 5, Fig. 6, and Fig. 7 illustrate the summary, waterfall, and force plots respectively generated by SHAP for the ORCA dataset. Table VI shows some feature values characteristic to AI and Human-generated texts.

TABLE VI. Some feature values characteristic to AI and Human-generated texts

| Feature | AI-Generated | Human Generated |
|---|---|---|
| Herdan's C | 0.9214 | 0.8901 |
| Simpson's Index | 0.016 | 0.013 |
| MATTR | 0.9548 | 0.9203 |
| Maas | 0.0180 | 0.0196 |
| Flesch-Kincaid grade level | 37.07 | 52.96 |
| Gunning Fog Index | 41.32 | 56.99 |
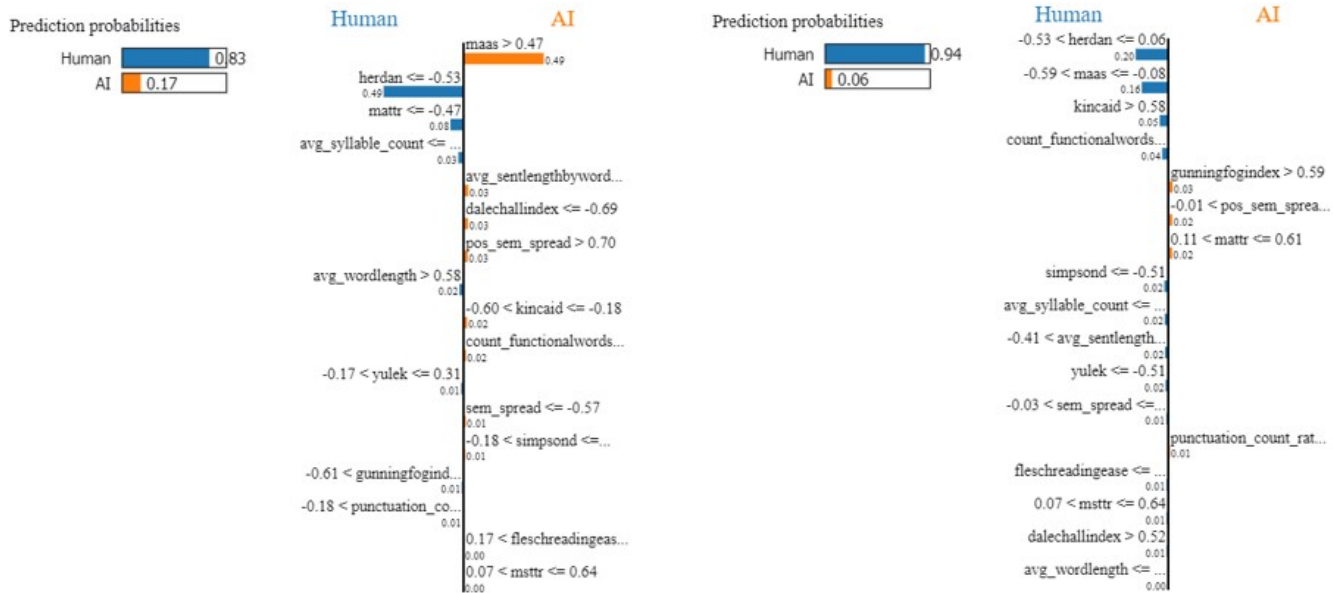
Fig. 4. LIME Interpretability Graphs for arbitrary human-generated texts



Fig. 6. Waterfall plot for SHAP values for Logistic Regression model trained on ORCA dataset



Fig. 5. Summary plot for SHAP values for Logistic Regression model trained on ORCA dataset



Fig. 7. Force plot for SHAP values for Logistic Regression model trained on ORCA dataset

## VII. CONCLUSION

In conclusion, this research delves into the intricate realm of AI-generated text analysis and its differentiation from human-generated text. As Artificial Intelligence continues to revolutionize various facets of human activities, including text composition, the challenges of identifying AI-generated content have become increasingly pertinent due to concerns about misinformation, security vulnerabilities, and identity theft. The research methodology is multifaceted, combining linguistic analysis, readability metrics, semantic spread measurements, and vocabulary richness assessments to uncover essential textual attributes. By leveraging a composite ensemble of machine learning models, including Logistic Regression, Decision Tree, Random Forest, Support Vector Classifier, and Gradient Boosting, the research demonstrates impressive efficacy with an accuracy of up to 93% in classifying AI-generated and human-generated text.

Moreover, the integration of xAI techniques, such as LIME and SHAP, provides invaluable insights into the features and patterns that influence the model's classification decisions. These insights reveal that certain attributes, such as Herdan's C, MaaS, and Simpson's Index, play pivotal roles in distinguishing AI-generated text from human-written content. These features highlight the richness of vocabulary, repetition of certain phrases, and syntactic patterns that are characteristic of AI-generated text.

The paper's limitation lies in its reliance on non-state-of-the-art models due to computational constraints, which may not fully represent the latest advancements in the field. These constraints, including limitations in computational resources and data availability, result in a performance gap compared to more advanced models. However, this limitation serves as a catalyst for future research that can harness the power of deep learning architectures and explainable AI (xAI) to delve into AI-generated text with greater sophistication. Additionally, it highlights the need to address ethical concerns and practical applicability as AI models evolve, making this paper a foundational stepping stone for deeper explorations in the future.

## VIII. FUTURE SCOPE

The research's future directions revolve around advancing AI-generated text analysis comprehensively. This entails harnessing larger and more diverse datasets spanning various domains, crucial for enhancing the detection system's real-world applicability. Alongside this, optimizing processing power to expedite analysis processes tied to xAI techniques like SHAP is essential. Incorporating additional style criteria such as linguistic tendencies and sentiment analysis aims to refine the methodology, deepening the grasp of distinguishing AI text styles from human language. This extends to evaluating a wider range of AI models beyond GPT-J and ORCA. Diversification of Machine Learning algorithms like K-Nearest Neighbors, Naive Bayes, and Neural Networks, as well as integration of Deep Learning algorithms like Transformer-based models, enhances AI text recognition. To fathom model decision-making, XAI methods like Grad-CAM and Integrated Gradients will be employed. Rigorous validation of authentic AI text data will test the proposed approach, collectively advancing differentiation between AI-generated and human-composed texts and propelling the field forward.

## REFERENCES

[1] P. Stone, R. Brooks, E. Brynjolfsson, R. Calo, O. Etzioni, G. Hager, J. Hirschberg, S. Kalyanakrishnan, E. Kamar, S. Kraus *et al.*, "Artificial intelligence and life in 2030: the one hundred year study on artificial intelligence," *arXiv preprint arXiv:2211.06318*, 2022.

[2] P. S. Park, S. Goldstein, A. O'Gara, M. Chen, and D. Hendrycks, "Ai deception: A survey of examples, risks, and potential solutions," *arXiv preprint arXiv:2308.14752*, 2023.

[3] E. Mitchell, Y. Lee, A. Khazatsky, C. D. Manning, and C. Finn, "Detectgpt: Zero-shot machine-generated text detection using probability curvature," 2023.

[4] N. Maloyan, , B. Nutfullin, E. Ilyshin, and and, "DIALOG-22 RuATD generated text detection," in *Computational Linguistics and Intellectual Technologies*. RSUH, jun 2022. [Online]. Available: https://doi.org/10.28995%2F2075-7182-2022-21-394-401

[5] N. Fairclough, "Discourse and text: Linguistic and intertextual analysis within discourse analysis," *Discourse & society*, vol. 3, no. 2, pp. 193–217, 1992.

[6] G. Jawahar, M. Abdul-Mageed, and L. V. S. Lakshmanan, "Automatic detection of machine generated text: A critical survey," 2020.

[7] S. Gehrmann, H. Strobelt, and A. M. Rush, "Gltr: Statistical detection and visualization of generated text," 2019.

[8] R. Goebel, A. Chander, K. Holzinger, F. Lecue, Z. Akata, S. Stumpf, P. Kieseberg, and A. Holzinger, "Explainable ai: The new 42?" in *Machine Learning and Knowledge Extraction*, A. Holzinger, P. Kieseberg, A. M. Tjoa, and E. Weippl, Eds. Cham: Springer International Publishing, 2018, pp. 295–303.

[9] H. Alamleh, A. A. S. AlQahtani, and A. ElSaid, "Distinguishing human-written and chatgpt-generated text using machine learning," in *2023 Systems and Information Engineering Design Symposium (SIEDS)*, 2023, pp. 154–158.

[10] G. Gritsay, A. Grabovoy, and Y. Chekhovich, "Automatic detection of machine generated texts: Need more tokens," in *2022 Ivannikov Memorial Workshop (IVMEM)*, 2022, pp. 20–26.

[11] C. H. Ng, H. S. Abuwala, and C. H. Lim, "Towards more stable lime for explainable ai," in *2022 International Symposium on Intelligent Signal Processing and Communication Systems (ISPACS)*, 2022, pp. 1–4.

[12] C. Tantithamthavorn, J. Jiarpakdee, and J. Grundy, "Explainable ai for software engineering," 2020.

[13] S. Chakraborty, A. S. Bedi, S. Zhu, B. An, D. Manocha, and F. Huang, "On the possibilities of ai-generated text detection," 2023.

[14] D. Beresneva, "Computer-generated text detection using machine learning: A systematic review," vol. 9612, 06 2016, pp. 421–426.

[15] D. Ippolito, D. Duckworth, C. Callison-Burch, and D. Eck, "Automatic detection of generated text is easiest when humans are fooled," 2020.

[16] R. Shijaku and E. Canhasi, "Chatgpt generated text detection," 01 2023.

[17] E. Vanmassenhove, D. Shterionov, and M. Gwilliam, "Machine translationese: Effects of algorithmic bias on linguistic complexity in machine translation," 2021.

[18] O. K. Kisselev and M. Aleksandr Kopotev, "A unified approach to interpreting model predictionsinvestigating lexical progression through lexical diversity metrics in a corpus of french l3," 2022.

[19] S. Lundberg and S.-I. Lee, "A unified approach to interpreting model predictions," 12 2017.

[20] S. Chowdhury and M. Schoen, "Research paper classification using supervised machine learning techniques," 10 2020, pp. 1–6.

[21] M. Chen, J. Tworek, H. Jun, Q. Yuan, H. P. de Oliveira Pinto, J. Kaplan, H. Edwards, Y. Burda, N. Joseph, G. Brockman, A. Ray, R. Puri, G. Krueger, M. Petrov, H. Khlaaf, G. Sastry, P. Mishkin, B. Chan, S. Gray, N. Ryder, M. Pavlov, A. Power, L. Kaiser, M. Bavarian, C. Winter, P. Tillet, F. P. Such, D. Cummings, M. Plappert, F. Chantzis, E. Barnes, A. Herbert-Voss, W. H. Guss, A. Nichol, A. Paino, N. Tezak, J. Tang, I. Babuschkin, S. Balaji, S. Jain, W. Saunders, C. Hesse, A. N. Carr, J. Leike, J. Achiam, V. Misra, E. Morikawa, A. Radford, M. Knight, M. Brundage, M. Murati, K. Mayer, P. Welinder, B. McGrew, D. Amodei, S. McCandlish, I. Sutskever, and W. Zaremba, "Evaluating large language models trained on code," 2021.

[22] R. E. Wright, "Logistic regression," 1995.

[23] A. J. Myles, R. N. Feudale, Y. Liu, N. A. Woody, and S. D. Brown, "An introduction to decision tree modeling," *Journal of Chemometrics: A Journal of the Chemometrics Society*, vol. 18, no. 6, pp. 275–285, 2004.

[24] A. Natekin and A. Knoll, "Gradient boosting machines, a tutorial," *Frontiers in neurorobotics*, vol. 7, p. 21, 2013.

[25] S. Suthaharan and S. Suthaharan, "Support vector machine," *Machine learning models and algorithms for big data classification: thinking with examples for effective learning*, pp. 207–235, 2016.

[26] S. J. Rigatti, "Random forest," *Journal of Insurance Medicine*, vol. 47, no. 1, pp. 31–39, 2017.

[27] R. J. Larsen, K. A. Mercer, and D. A. Balota, "Lexical characteristics of words used in emotional stroop experiments." *Emotion*, vol. 6, no. 1, p. 62, 2006.

[28] C. van der Lee and A. van den Bosch, "Exploring lexical and syntactic features for language variety identification," in *Proceedings of the Fourth Workshop on NLP for Similar Languages, Varieties and Dialects (VarDial)*, 2017, pp. 190–199.

[29] A. C. Bale and D. Barner, "The interpretation of functional heads: Using comparatives to explore the mass/count distinction," *Journal of Semantics*, vol. 26, no. 3, pp. 217–252, 2009.

[30] J. P. Kincaid, R. P. Fishburne Jr, R. L. Rogers, and B. S. Chissom, "Derivation of new readability formulas (automated readability index, fog count and flesch reading ease formula) for navy enlisted personnel," 1975.

[31] S. Zhou, H. Jeong, and P. A. Green, "How consistent are the best-known readability equations in estimating the readability of design standards?" *IEEE Transactions on Professional Communication*, vol. 60, no. 1, pp. 97–111, 2017.

[32] D. Świeczkowski and S. Kułacz, "The use of the gunning fog index to evaluate the readability of polish and english drug leaflets in the context of health literacy challenges in medical linguistics: An exploratory study," *Cardiology Journal*, vol. 28, no. 4, pp. 627–631, 2021.

[33] L. P. Stocker, "Increasing the precision of the dale-chall readability formula," *Reading Improvement*, vol. 8, no. 3, p. 87, 1971.

[34] J. A. Smith and C. Kelly, "Stylistic constancy and change across literary corpora: Using measures of lexical richness to date works," *Computers and the Humanities*, vol. 36, pp. 411–430, 2002.

[35] S. Herdan and Y. Sharvit, "Definite and nondefinite superlatives and npi licensing," *Syntax*, vol. 9, no. 1, pp. 1–31, 2006.

[36] J. Treffers-Daller, "Measuring lexical diversity among l2 learners of french," *Vocabulary knowledge: Human ratings and automated measures*, vol. 47, 2013.

[37] N. Chipere, D. Malvern, B. Richards, and P. Duran, "Using a corpus of school children's writing to investigate the development of vocabulary diversity," in *Technical Papers. Volume 13. Special Issue. Proceedings of the Corpus Linguistics 2001 Conference*. Citeseer, 2001, pp. 126–133.

[38] S. Jarvis, "Capturing the diversity in lexical diversity," *Language Learning*, vol. 63, pp. 87–106, 2013.

[39] Y. Anand, Z. Nussbaum, B. Duderstadt, B. Schmidt, and A. Mulyar, "Gpt4all: Training an assistant-style chatbot with large scale data distillation from gpt-3.5-turbo," https://github.com/nomic-ai/gpt4all, 2023.

[40] C. Goutte and E. Gaussier, "A probabilistic interpretation of precision, recall and f-score, with implication for evaluation," in *European conference on information retrieval*. Springer, 2005, pp. 345–359.

[41] A. Daniele, C. Di Bernardi Luft, and N. Bryan-Kinns, ""what is human?" a turing test for artistic creativity," in *Artificial Intelligence in Music, Sound, Art and Design: 10th International Conference, EvoMUSART 2021, Held as Part of EvoStar 2021, Virtual Event, April 7–9, 2021, Proceedings 10*. Springer, 2021, pp. 396–411.

[42] N. C. Chung, "Human in the loop for machine creativity," *arXiv preprint arXiv:2110.03569*, 2021.

# A Small Dummy Disrupting Database Reconstruction in a Cache Side-Channel Attack

Hyeonwoo Han[1], Eun-Kyu Lee[2]*, Junghee Jo[3]

Department of Information and Telecommunication Engineering,
Incheon National University, Incheon, Korea[1,2]

Department of Computer Education, Busan National University of Education, Busan, Korea[3]

*Abstract*—This paper demonstrates the feasibility of a database reconstruction attack on open-source database engines and presents a defense method against it. We launch a Flush+Reload attack on SQLite, which returns approximate, noisy volumes returned by range queries for a private database. Given the volumes, our database reconstruction uses two algorithms, a Modified Clique-Finding algorithm and Match-Extension algorithm, to recover the database. Experiments show that an attacker can reconstruct the victim's database with a size of 10,000 and a range of 12 with an error rate of up to 0.07% at most. To mitigate the attack, a small dummy data is added to the result volumes of range queries, which makes the approximation more confused. Experimental results show that by adding about 1% of dummy data, an attack success rate (in terms of the number of reconstructed volumes in the database) is reduced to 60% from 100% and an error rate increases to 15% from 0.07%. It is also observed that by adding about 2% of dummy data, the reconstruction is completely failed.

*Keywords*—*Attack; cache attack; side-channel attack; security; database reconstruction; privacy; clique-finding; database volume*

## I. INTRODUCTION

Data processing continues to become more common in the cloud, and cloud computing is embedded in the business model of popular services such as Google's G Suite, Microsoft's Office 365, Adobe Creative Cloud [1]. In addition to cloud use by industry, federal agencies are also now leveraging cloud services, even for the storage and analysis of sensitive data. Microsoft, for example, won a $10 billion contract from US government that creates a secured cloud for the Pentagon.

One of the most significant security challenges in the cloud is on processing sensitive information. In extreme cases, cloud servers that handle sensitive information may not be trusted because they are presumed to be malicious. In this case, since the data must be encrypted, additional time is required to calculate the encrypted data [2], [3]. In this paper, it is assumed that a trusted server handles sensitive data, but a spying process is also running on the same public server. When the spy process is located in the same physical space as the victim, it shares hardware such as cache, which may act as a side channel. Our assumption is quite reasonable in a realworld setting because leading companies in the cloud service spend great amount of money to show that their servers are trusted.

The goal of this paper is to investigate the impact of side-channels on open-source database engines, to address the risks, and to present a method for defense. The model of the paper assumes that an external user requests a query a private database stored in the victim Virtual Machine (VM), and that the victim VM uses SQLite to process the query and returns the result to the external user. An attacker cannot make a query request directly to the database or observe the results of the query. The attacker is running a spy VM in the cloud with the victim VM, so it can monitor the shared cache to bring in side channel leaks. The attacker's goal is to reconstruct the volume of the victim's database. Reconstruction of the database here refers to recovering the volume rather than finding out all the information correctly. Suppose that a school's student database stores data from <Alice, Bob, Charlie> for grade $A$, <Dave, Eve> for grade $B$, <Frank, George, Henry, Ivan> for grade $C$, for example. The reconstruction is to restore the volume of three rows for grade $A$, two rows for grade $B$, and four rows for grade $C$.

This paper introduces a conventional side-channel attack that captures information leakage in the cache shared by victim VMs and a spy VM using SQLite. This recovers approximate volumes of database including some noise values. We also introduce a database reconstruction attack that uses a clique finding algorithm. It recovers database volumes by constructing a graph based on correct and noiseless volumes of the range queries. In order to make it deal with the approximate, noisy volumes, this paper shows its extension. The extended algorithm includes two sub algorithms. In a modified clique finding algorithm, a concept of noise budget is introduced and utilized in a edge creation step of the clique finding algorithm. A match-extension algorithm handles such a case that the modified algorithm sometimes fails to find a maximum clique in a given graph. Experimental results show that our database reconstruction can recover almost 100% volumes of database with low error rate (0.2-0.7%).

To mitigate the database reconstruction attack, this paper introduces a stratey to add noise to data. The intution behind the strategy is that the clique finding algorithm is an NP-Hard problem. The complexity of the algorithm grows quickly with the size of the range. Thus, adding a small number of nodes to a graph can significantly increase the time required to reconfigure the database; it can even cause the algorithm to fail completely. Technically, a small dummy data is added to the results of range queries. This approach is reasonable in that approximate volume data obtained from the side-channel attack is only exposed to attackers and they are not aware of the existence of dummy data. Regular users (in victim VMs) is able to access raw data and easily seperate the dummies before processing further. Experiments were conducted to investigate

the impact of the noise (dummy data) on performance of database reconstruction. With 1% of dummy data, only 60% of database were recovered with up to 15% of error rate. When adding 2% of dummy data, no databased was constructed at all; the database construction attack was completely failed.

The rest of the paper is organized as follows. Section II reviews previous research outcomes in cache attacks and database construction attacks. Section III describes a threat model, a cache side-channel attack, that this paper addresses. In Section IV, we introduce a database construction attack that aims to recover the volume of orginal database given noisy data obtained from the cache side-channel attack. Section V introduces a mitigations strategy, which is followed by experiments and results in Section VI. Finally, Section VII concludes the paper.

## II. RELATED WORKS

Cache attack is performed based on attacker's ability to monitor cache accesses made by the victim in a shared physical system as in virtualized environment or a type of cloud service [4]. Tsunoo et al. [5] introduced it first by showing a timing attack caused by collisions in the memory lookups on a block cipher. Osvik et al. [6] revealed an inter-process leakage via cache's state and showed key extraction of AES. Acıiçmez [7] showed that instruction cache could be a target for attacks. Ristenpart et al. [8] explored the feasibility of side channel attacks on cloud; they demonstrated that an attacker could penetrate VM isolation and harm confidentiality of victim VMs. In [9], authors introduced a cache side-channel attack technique, Flush+Reload, that exploited weakness of memory pages shared among processes. Cache behaves in a way to leak information on a victim's access to memory lines in shared pages; so that an attack can determine what victim does and infer the data the victim operates on. They also showed that the technique could be used to extract cryptographic keys for RSA. By using the Flush+Reload, Yarom and Benger [10] demonstrated that the ECDSA leaked the nonce and the secret key of the signer, allowing unlimited forgeries. Moghimi et al. [11] introduced an attack tool, CacheZoom, that could allow an attacker to monitor all memory accesses of SGX enclaves with high resolution. They demonstrated the feasibility of AES key recovery. Authors in [12], [13], [14] showed possibility of cache side-channel attacks by monitoring critical operations in AES T-table entry and other operations such as modular exponentiation, multiplication, or memory accesses. Yan et al. [15] used Prime+Probe and Flush+Reload for the cache side channel and successfully obtained a DNN's architecture that was considered a major commercial asset in a business. Hong et al. [16] showed a DNN fingerprinting attack where an attacker followed function invocations corresponding to architecture attributes of the victim network and thus fingerprinted the entire network.

In database reconstruction, Kellaris et al. [17] demonstrated reconstruction attacks on securely outsourcing database storage systems implementing searchable symmetric encryption or order-preserving encryption. Their attacks were developed for a weak adversarial model where underlying query distribution was only known to an attacker. He does not directly query a database and not need to know any of queries nor answers; he may observe encrypted resonses of queries. They identified that

either access pattern or communication volume was leaked for range queries. A reconstruction attack run with the auxiliary information in $N^4$ queries, where $N$ is a domain size, which recovered the number of records having each specific value in a database, i.e., database counts. Lacharité et al. [18] considered a setting where access pattern (a set of records matched by each query) and rank information (the position of a record in a sorted list of records) were leaked. They presented three attacks, full reconstruction, approximate reconstruction, and reconstruction using auxiliary information, that recovered values in different levels of accuracy. Grubbs et al. [19] presented a database reconstruction attack given the volume leakage of the response of range queries. Their attack used a graph-theoretic approach; they reduced database reconstruction to finding a clique in a graph constructed from the volume information. In the graph, volumes were represented as nodes, and an edge connected two nodes when their absolute difference was represented as a node. After multiple iterations of adding and deleting nodes, their algorithm returned the counts of all values in the database. Shahverdi et al. [20], unlike prior a threat model, considered an honest cloud server on which an adversary virtual machine and a victim one co-located. The adversary could not issue queries to the victim's database but obtain information leaked via a shared cache. This implies that he could not obtain response volumes of range queries accurately; instead, obtaining noisy volumes. In this scenario, authors presented a database reconstruction attack by extending the Grubbs's algorithm [19] and by developing a noise reduction algorithm.

Naveed et al. [21] showed attacks on database systems capturing property-preserving encryption. Using encrypted database columns and publicly known auxiliary informtion, they could recover certain encrypted attributes by up to 80%. Kornaropoulos et al. [22] considers an encrypted spatial database that handles data in a geometric space and k-nearest neighbor (kNN) queries that return the nearest k points in the database for a given query point based on distances between points. Authors exploited a query leakage profile and used a convex polytope to characterize a set of reconstructions. The attack could recover values of the database with approximation error of 2.9% to 0.003%. The same authors in [23] developed a reconstruction attack without assumptions about the knowledge of query distribution and the data. The attack exploited search-pattern leakage, computed distances between encrypted values, and eventually recovered plaintext values.

## III. THREAT MODEL: CACHE SIDE-CHANNEL ATTACK

A threat model in this paper assumes multiple users in a cloud server, each of which has access to its own database. For instance, it is assumed that user 1 can access database 1, user 2 can access database 2, and server is a trusted server. Once one of the users becomes an attacker with a malicious intend, he can abuse physical properties of the model; his VM is in the same cloud server and shares the cache with victim VMs. Although an attacker cannot directly query the database of a victim, he can interact with the server to obtain some information about the inaccessible database.

The attacker does not know what range of queries were requested and what rows were returned exactly. This means that only an approximate volume with noise can be obtained.
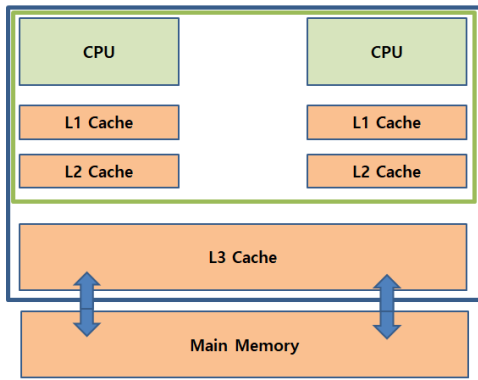
Fig. 1. A general cache architecture.

It is noted that the side-channel attack proceeds regardless of whether the victim's database is encrypted or not, as it proceeds by approximating the volume of range queries. An attack is possible as long as the spy VM can see the code line that the database engine executes for each record returned in the range query.

### A. Cache Architecture

Cache is a memory located at the top of the memory hierarchy. It is much smaller in size than the main memory and is very expensive, but it is characterized by a very fast speed. The cache is placed between the CPU and the main memory as shown in Fig.**??**. Data in the main memory is loaded into the cache memory, and performance can be expected to be improved by allowing the CPU to access the cache memory first instead of the main memory with relatively slow access time. The cache serves as a buffer to reduce the speed gap between the CPU and the main memory.

Typical modern CPUs have multiple levels of cache to reduce access time to the main memory. Level 1 cache is the smallest and fastest, while Level 3 cache forms the slowest and largest hierarchical structure. Level 1 cache is divided into two caches, one to store data and the other to hold instructions. In higher-level caches, data and instructions are kept in the same cache. Level 3 cache is a shared memory space where data and instructions are kept in the same cache and is the Last Level Cache (LLC). The LLC includes all lower level architectures, which means that all data present in Level 1 and Level 2 also exists in the LLC. Each cache consists of multiple sets, each set containing multiple cache lines. Each line in the main memory is mapped to a unique set of caches. However, within this set, memory lines can be mapped to cache lines. Typically, each cache line stores 64 bytes of data. If it's already full, we have to decide which memory lines to be removed when writing new lines. This decision is called the Replacement Policy and depends on a cache structure. The most popular replacement policy is the Least-Recently Used (LRU), which replaces the least recently used items with new ones.

### B. Flush + Reload Attack

Cache is vulnerable to information leakage because an attacker that is with the victim on the same process can access meaningful information about activities of the victim. In particular, an attacker can monitor and use his own access time to the cache to guess whether the victim has accessed specific memory lines. The reason why such an attack is possible is that the attacker and the victim share the same resource, that is, the cache. Moreover, in a setting where the attacker and victim share the library, both will have access to the physical memory location where a single copy of the library is stored. An attacker can explicitly remove lines corresponding to shared physical memory from the cache. In order to exploit the shared physical memory in a useful way, this paper uses a *Flush+Reload* attack introduced by Yarom and Falkner [9].

This attack method takes advantage of the fact that the access time to cache memory is shorter than that to main memory, and targets the L3 cache line shared by a victim and an attacker. An attacker uses a special command called `clflush` to remove a monitored line from the cache. This command removes the monitored line from the L1, L2, and L3 caches. As mentioned earlier, L3 includes L1 and L2. Thus, if L3 is removed, the lines that are removed are removed from all other caches. The attacker then allows the victim to continue running a program. After a certain period of time, the attacker regains control and measures the memory access time to determine whether the monitored line still remains in the cache. If the reload runs quickly, the monitored line is still in the cache. Then, an attacker deduces that the victim accessed the same line during execution. If the reload runs slowly, the monitored line is not in the cache. Then, the attacker infers that the victim did not access the line while running. Thus, an attacker can know whether the victim has accessed a particular line. To perform the *Flush+Reload* attack, this paper used a package provided in the Mastik framework [24]. Mastik is a toolkit for experimenting with micro-architectural side-channel attacks and provides implementations of published attack and analysis techniques.

### C. Detecting Two Lines to Monitor

This paper uses SQLite [25], a popular open-source database engine that uses the BTree data structure to store columns. We looked into the SQLite program and used a `gcov` command to detect a line being called once in each iteration of the range query. It is possible to determine query response volume by monitoring the number of times these rows are called. It should be noted that the duration of each query can also be measured and used as an indicator of the volume. However, there is no reliable way to convert time to volume, resulting in introducing big noise. So we decided to count the numbers explicitly. The library was compiled using the `-fprofile-arcs` and `-ftest-coverage` flags to obtain the number of times each line runs. We, then, ran the range query command and used the `gcov` command to count the number of times each line was executed in the main.c and sqlite3.c files. After finding more lines in the SQLite program, two lines are monitored simultaneously to improve measurement accuracy. The advantage of monitoring two lines is as follow. Even if an attack code may fail to detect activity on one of the lines due to overlap between the attacker reload and victim access, it is still likely to see activity on the second line. There may be some false positives due to the mismatch of hits on the two lines, which is mitigated by considering the number of proximity hits to be from the same activity.
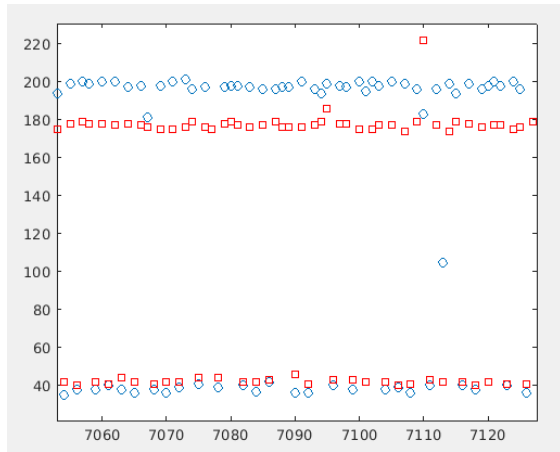
Fig. 2. We launched the Flush+Reload attack on SQLite and showed one sample measurement; the two monitored lines are shown in blue and red.

### D. Using Mastik Toolkit

After detecting a line leaking query volume, we, by using the Mastik Toolkit, monitor the lines while SQLite processes range queries. Fig. **??** draws results of one sample measurement. The two lines being monitored are colored blue and red. The x-axis represents the sample point at which the reload occurs, and the y-axis represents the time required to reload the monitored line from memory on that time instance. Because two lines are being monitored, there are two sets of measurements for each time instance.

A `FR-trace` utility in Mastik automatically starts measuring when it detects a hit on one of the lines monitored by the SQLite program. When Mastik does not detect more activities for a while, the measurement automatically end. There are samples with reload time of less than 100 cycles during the interval in which the range query runs. These sample points are recorded when SQLite accesses the line the attacker is monitoring, so the attacker sees a small reload time. Then the number of hits in blue or red measurements are calculated. The number of hits corresponds to the inquiry volume. It is also important to monitor the associated cache lines in order to detect when/whether the range query is executed. Because the measurement is not a noise-free environment, the number of hits counted may differ from the actual value of the volume. Some of the sources of noise are explained below.

*False Positive (FP)*. Instruction to be executed are brought into the cache before memory lines are executed. In the case of the Flus+Reload attack, it still looks that this instruction was executed because of the fast access. In general, true hit counts occur at fixed time intervals. If observing a hit that occurred much earlier than the expected hit time, it is likely a FP. It is presumed to have occurred by speculative execution, and it is not considered to be hit.

*False Negative (FN)*. A FN occurs when the victim accesses the monitored code line after the spy process reloads the line and before the spy process flushes the line. This paper attempts to detect FNs only algorithmically; an asymmetric window around each observed volume is used to compensate for the fact that the actual volume is usually larger than the observed volume. In our experiments, we assign 90% of the window width to a value larger than the observed volume.

### E. Approximate Noisy Volumes

A single trace is collected by randomly selecting and executing a range query [a, b] while simultaneously monitoring the line using Mastik FR-trace. This experiment is repeated several times to collect enough traces. We count, for each trace, the number of times that one of the two lines represents a hit, mitigate the FP problem, and then report the number of hits as a range query volume for that trace. Some volumes are observed much more frequently than others, and their values are stored as approximations to the expected volumes. It is expected to see $\binom{N}{2} + N$ values at most in a noiseless setting. There are some traces noted *good enough* but with incorrect volume. By putting all traces together, the effect of such instances would be minimal and the exact approximation of the volume would be distinguishable. It is noted that the volume being recovered is an approximate volume of the database, not a correct volume.

## IV. DATABASE RECONSTRUCTION

Given a set of volume of database recovered from the cache side-channel attack, the attacker aims at reconstructing the database. This section explains our database reconstruction based on a clique finding algorithm. It shows, first, the Grubbs' work [19] that constructs a graph based on the observed correct and noiseless volumes of the range queries. Note that each volume is represented by a node in a graph. Then, an extention of the clique finding algorithm to handle noisy volumes [20] is introduced.

### A. Clique Finding without Noise

The clique finding algorithm has two main parts for graph construction: node creation and edge creation.

*1) Creating Nodes:* Given a set of recovered volumes V, this part creates a node representing each volume and labels the node with that volume. This means that node $v_i$ has volume $v_i$.

A recovered volume refers to a volume that has been reconstructed through an attack. Suppose that we have a <5,10,15,20> database of size 4. A query request with a range of 1 will return 5 rows, and a query request with a range of 1 to 2 will return 5 + 10 = 15 rows. It returns 10 + 15 + 20 = 45 rows if a user asks for a query of 2 to 4. From the attacker's point of view, it is not possible to know exactly what range the query request is, but it can be seen that the volume returned is {5,10,15,20,25,30,35}. These volume sets are called recovered volumes.

*2) Creating Edges:* This part creates an undirected edge between two nodes $v_i, v_j \in V$ if there exists a node $v_i \in V$, where $v_i = v_j + v_k$.

A volume can be recovered by running a clique finding algorithm on the constructed graph. Assuming the value ranges from 1 to N, there are $\binom{N}{2} + N = \frac{N(N+1)}{2}$ possible ranges, so the graph shows $\frac{N(N+1)}{2}$ nodes. Each range $[i, j]$ for $1 \le i \le j \le N$ is denoted by a node. In other words, node $[i, j]$ means
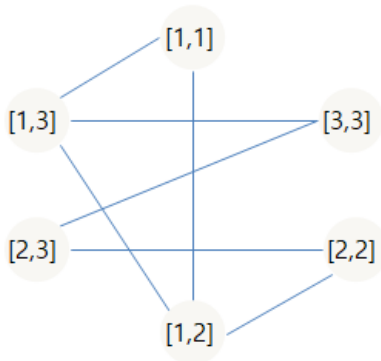
Fig. 3. A graph constructed with nodes of ranges.
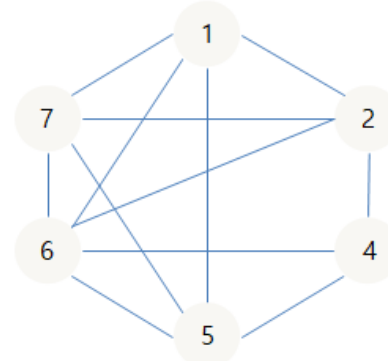


Fig. 4. A graph constructed with nodes of volumes corresponding to Fig. **??**.

that the range of the query is $i$ to $j$. Nodes corresponding to ranges of of the form $[1, i]$ for $1 \leq i \leq N$, i.e., base volumes, forms a clique for pairs of ranges of $[1, i]$ and $[1, j]$ ($1 \leq i \leq j \leq N$). There is a range of $[i + 1, j]$. This means that there exists an edge between $[1, i]$ and $[1, j]$ due to the way the graph is constructed. The clique finding algorithm finds nodes $[1, i]$, $1 \leq i \leq N$. In order to recover the original range of form $[i, i]$, we simply sort the nodes based on labels and subtract them sequentially because $|[i, i]| = |[1, i]| - |[1, i - 1]|$, $1 < i \leq N$.

| Student name | Alice | Bob | Charlie | Dave | Eve | Frank | George |
|---|---|---|---|---|---|---|---|
| Grade | 1 | 2 | 2 | 2 | 2 | 3 | 3 |

For instance, suppose a student database shown in Table I. A set of known ranges and corresponding observed volumes are $[1, 1] = 1$, $[2, 2] = 4$, $[3, 3] = 2$, $[1, 2] = 5$, $[2, 3] = 6$, $[1, 3] = 7$. Fig.**??** shows that a graph is constructed based these data, where each node represents a range. The edge creation part created lines connecting two nodes. Since $|[1, 2]| = |[1, 1]| + |[2, 2]|$ and there exists a node $[2, 2]$ connecting $[1, 1]$ and $[1, 2]$, the two nodes are connected via a line. Similarly, $|[1, 3]| = |[1, 2]| + |[3, 3]|$, so there is a connection between $[1, 3]$ and $[3, 3]$.

It is observed that three nodes $[1, 1]$, $[1, 2]$, and $[1, 3]$ in the graph are connected each other and form a complete graph. A subset of nodes in which every two different nodes in an undirected graph are connected is called a clique. Among the cliques that can be found, the largest clique becomes the clique of the graph. Upon finding the clique, $[2, 2]$ can be obtained by subtracting $[1, 1]$ from $[1, 2]$, and $[3, 3]$ by subtracting $[1, 2]$ from $[1, 3]$. This allows us to reconstruct the database easily. Although the exact range is unknown, if the $\{1, 4, 2, 5, 6, 7\}$ volume set is recovered through an attack, it is possible to find $1, 5, 7$ cliques as shown in Fig. **??** and reconstruct the database in the same way.

### B. Modified Clique Finding with Noise

From the cache side-channel attack in Section III, correct volumes may not be recovered; that is, recovered ones are approximate and noisy volumes. Therefore, a conventional clique finding algorithm that assumes noiseless volumes (described in

Section IV-A) does not find cliques of sufficiently large size. This happens because the condition for connecting nodes $v_i$ and $v_j$ almost always fails since it is not possible to find the third volume $v_k$, where the equation $v_i = v_j + v_k$ is satisfied. This implies that too many edges are missing in the constructed graph to form large cliques.

To mitigate the effect of noise, our method modifies the second parts (Creating Edges) in the clique finding algorithm, a *Modified Clique-Finding algorithm*. Because traces are noisy, it may not possible to obtain the correct volume. The recovered volume is close to the correct volume, and error ranges can be calculated. Here, we define a *noise ratio* as (the recovered volume / the correct volume). An attacker, at the first step, performs a preprocessing by launching an attack on a database known to the attacker. The attacker then examines the recovered volume, selects a noise ratio, and compares it with the actual volume, from which he evaluates the accuracy of the traces to find an approximate value for the noise ratio. Based on all the noise ratios, the attacker then sets a value for *noise budget* - the average of the noise ratios observed across all volumes. The attacker, once the noise budget is fixed, then creates a window of acceptable values around it for each recovered volume. The window is created around $v_i$ using lower bound of $v_i \times (1 - 0.1 \cdot noise\ budget)$ and upper bound of $v_i \times (1 + 0.9 \cdot noise\ budget)$. The window is asymmetric with 90% of the width on the right side because the noisy volume is usually smaller than the actual volume. For volume $v_i$, the window is denoted as $w(v_i)$. The modified part in the clique finding algorithm that enables to construct a graph from nosiy volumes is as follow.

- *Creating Edges (Modified):* This part creates an undirected edge between two nodes $v_i, v_j \in V$ if there exists a node $v_k \in V$, where $|v_i - v_j| \in w(v_k)$.

### C. Match-Extension

Although the noise budget is appropriately adjusted, the Modified Clique-Finding algorithm sometimes fails to find the maximum clique of size $N$. This section describes an improvement of the algorithm to handle such a case. First, note that in the clique finding algorithm, a graph corresponding to the volume in the range $[1, i]$ for $1 \leq i \leq N$ should have a clique if there is a full range of volumes present in the data.
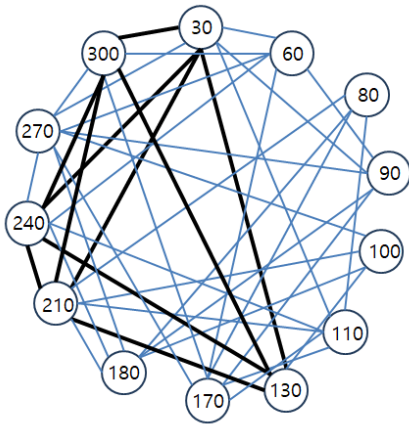
Fig. 5. A graph constructed from noiseless volumes in the database <30, 100, 80, 30, 60>. The maximum cliques corresponds to $N$, 5. The maximum cliques found are shown in bold connections.
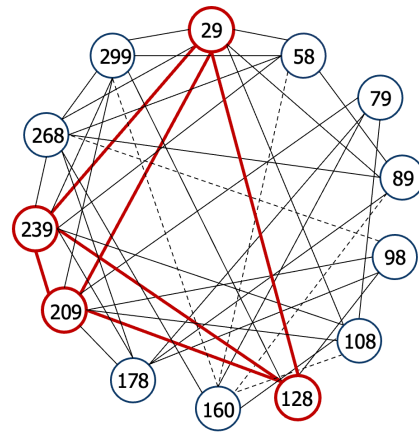


Fig. 7. Given a graph missing edges, the Modified Clique-Finding algorithm returns a clique of size 4 (less than $N$ = 5) with values {29, 128, 209, 239}.
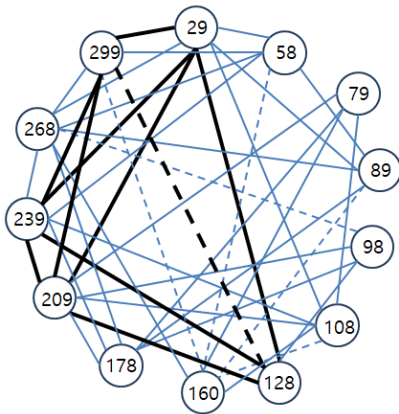


Fig. 6. A graph constructed from noisy volumes in the database <30, 100, 80, 30, 60>. A missing edge in the maximum clique is represented in the dotted line.

Now suppose we are given an approximate, noisy volume corresponding to the range $[i, j]$. $|[1, i]| \approx |[1, i-1]| + |[i, j]|$ should have a connection, but the connection from node $[1,j]$ to node $[1,i-1]$ is missing. A maximum clique of size $N$ is not formed as a result of missing connections. Executing the clique finding algorithm on data with missing volumes returns cliques of size smaller than $N$ and recovers the candidate database for each clique. The algorithm then merges information from these small databases to create a larger database.

*1) Observation:* This subsection explains the idea of this improvement with an example. Consider a database with a range of 5 possible values (i.e., $N$ = 5), <30, 100, 80, 30, 60>. This means $|[1, 1]| = 30$, $|[2, 2]| = 100$, $|[3, 3]| = 80$, $|[4, 4]| = 30$, $|[5, 5]| = 60$. A set of possible values for the volume of range queries $V$ is, then, {30, 60, 80, 90, 100, 110, 130, 170, 180, 210, 240, 270, 300}. For instance, $|[1, 2]| = 130$. A graph constructed for these volumes is shown in Fig. 5. The maximum cliques found by the algorithm are shown in bold connections. The nodes {30, 130, 210, 240, 300} are returned, and a database <30, 100, 80, 30, 60> is reconstructed.

Now, assume that the recovered volume has noise and that a set of possible values for the volume of range queries $V$ is {29, 58, 79, 89, 98, 108, 128, 160, 209, 239, 268, 299} as shown in Fig. 6. Almost all the noisy volumes are close to the true values; exceptionally volume 160 is far from the correct volume 170. In this setting, our method uses the Modified Clique-Finding algorithm to construct a graph. It first uses a window around a volume $v_i$ allowing to have lower and upper bounds of $v_i - 1$ and $v_i + 3$, respectively. Some connections will be missing due to measurement errors. For example, a connection from node 299 to node 128 will not be formed because there is no window containing 171 anymore. If our method runs the algorithm on the new graph, the result will be a smaller clique (less than $N$ = 5). As shown in Fig. 7, the algorithm returns cliques whose size is 4 with values {29, 128, 209, 239}, which creates a database $< 29, 99, 81, 30 >$. In the next, we describe main steps in the Match-Extension algorithm to reconstruct a database from noisy volumes.

*2) Finding cliques:* This step aims at finding all the cliques in the constructed graph.

**Maximum Clique**. The first stage is to find the maximum clique in the graph. Let $K$ be the size of the maximum clique recovered in this stage. If multiple cliques with the same maximum size are found, one of them is chosen randomly. Once a clique is found, a corresponding database is reconstructed. We call this database an initialized solution, `initSolution`. If the size of the maximum clique found in this stage is $N$, it is done; the database is successfully reconstructed. Otherwise, the rest parts of the algorithm extend this `initSolution`.

**All Other Cliques**. The next stage recovers all cliques of sizes $K, K - 1, K - 2, \ldots,$ and $K - l$, and sorts them from the largest size to the smallest size. For each clique, a corresponding database is reconstructed and referred to as a candidate solution `candSolution`. It is in the form of a sorted list of volumes corresponding to contiguous ranges in the database. The cliques found in this stage are not limited to ranges of the form $[1, 1], [1, 2], \ldots, [1, K]$ for some $K$. Note that this holds true even in the noiseless setting. Any set of volumes in the range of $[i, i_1], [i, i_2], \ldots, [i, i_k]$, where $i \leq i_1 < i_2 < \cdots < i_k$, forms a clique of size $k$ if all
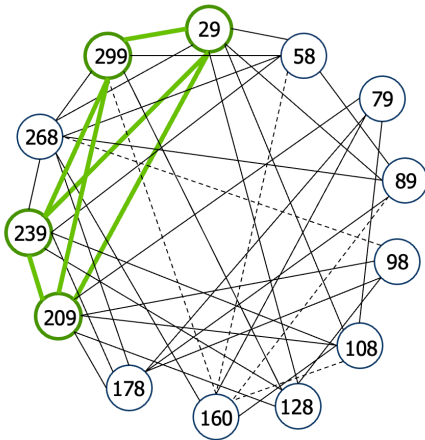
Fig. 8. The Modified Clique-Finding algorithm returns a clique with values
$\{29, 209, 239, 299\}$ (size = 4), which creates a database $\langle 29, 180, 30, 60 \rangle$

.

differences in volumes corresponding to the ranges exist in the data. This fact allows this algorithm to recover the original database by discovering the volumes of different parts of the actual database and combining those parts.

*3) Combining solutions:* Given the `initSolution` and a `candSolution` in the form of lists of volumes, in this step, the Match-Extension algoriithm *combines* the information in them into one large solution.

**Longest Common Substring** The first stage is to find the longest common substring of the two solutions; it is the longest contiguous list of volumes where the two solutions match. We call this substring `lcList`. To find it, our method uses a modified standard longest common substring algorithm where the elements of the substring are approximately equal to the corresponding elements of `initSolution` and `candSolution`. This stage returns the `lcList` and the starting and ending indices (locations) of `lcList` in two given solutions. However, even after the first stage, there may be volumes where `initSolution` and `candSolution` match, which are not recognized in the first stage. In order to show an example, we take the previous sample from Fig. 7 and let the `initSolution` $\langle 29, 99, 81, 30 \rangle$. `candSolution` is $\langle 29, 180, 30, 60 \rangle$ (see Fig.8 for its construction). In this case, `lcList` can be found as $\langle 29 \rangle$, but it is observed that the two solutions match at $\langle 99, 81 \rangle$. This information is presented as a volume of a range $\langle 180 \rangle$ that is the union of two adjacent ranges in `initSolution`.

**Extension** Our combine algorithm identifies such a case and extends `lcList` accordingly in the next stage. It searches for cases where a particular volume $v_i$ next to the end of `lcList` in one solution (say `initSolution`) is approximately equal to the sum of the volumes $u_j, u_{j+1}, \ldots, u_{j+r}$ if $r \geq 0$ next to the end of `lcList` of the other solution (e.g. `candSolution`). The algorithm, then, extends the `lcList` by adding $\langle u_j, u_{j+1}, \ldots, u_{j+r} \rangle$ and changing the endpoints of the `lcList` in `initSolution` and `candSolution`. In the database example above, the combine algorithm examines the neighbors of $\langle 29 \rangle$ and finds that $180 \approx 99 + 81$, and extends the `lcList` to $\langle 29, 99, 81 \rangle$. It again examines the

neighbors of $\langle 29, 99, 81 \rangle$ and finds $30 \approx 30$, extending the `lcList` to $\langle \mathbf{29, 99, 81, 30} \rangle$. It is noted that while the values in the example are exactly the same (e.g., $180 = 99 + 81$) by chance, the algorithm also accepts the case where values are approximately equal.

```
initSolution = ⟨prefix1, lcList, suffix1⟩
candSolution = ⟨prefix2, lcList, suffix2⟩
```

After the `lcList` is maximally extended, the two solutions have the form above. Any of prefixes and/or suffixes can be empty. The algorithm then performs one of four options:

(a)   If `prefix1` and/or `suffix1` is empty, then it extends the `lcList` to `lcList = prefix2||lcList` and/or to `lcList||suffix2`.

(b)   If `prefix2` and/or `suffix2` is empty, then it extends the `lcList` to `lcList = prefix1||lcList` and/or to `lcList||suffix1`.

(c)   If the lengths of both `prefix1` and `prefix2` are 1 (say, their volumes are $a$ and $b$, with $a < b$), and if the absolute value of difference appears in the volume measurement, then `lcList = ⟨b−a, a⟩||lcList`. This option also applies to the case when the lengths of both `suffix1` and `suffix2` are 1.

(d)   Otherwise, the algorithm stops combining and repeats stages for another `candSolution`.

Back to our example, we found the `lcList` to be $\langle \mathbf{29, 99, 81, 30} \rangle$. The last stage has `initSolution` $= \langle \text{lcList} \rangle$ and `candSolution` $= \langle \text{lcList}, 60 \rangle$. This is the case of option (a) where `suffix1` is empty. Thus, the algorithm adds `suffix2` $= \langle 60 \rangle$ to `lcList` and returns `initSolution` $= \langle \mathbf{29, 99, 81, 30, 60} \rangle$ as a solution.

*4) Finding best solution:* Once a combine is successful, two solutions are merged and one larger solution is created. The clique finding algorithm may not discover this large solution in the first place because some volumes or connections in the graph were missing, preventing potential cliques corresponding to this solution from being formed. Whenever two solutions are combined, it identifies the number of missing volumes that prevented finding the combined solution. In fact, if the missing volumes could be added to the graph and starts the algorithm, we could get the combined solution in all listed solutions. Therefore, the number of missing volumes is used as a metric to evaluate how good a candidate solution is. On one hand, showing few missing volumes indicates that the `initSolution` and `candSolution` match on many volumes in the database and therefore are compatible. On the other hand, a large number of missing volumes suggests that two solutions may have different information about the volumes. At this, last step finds a candidate solution among all cliques having the lowest number of missing volumes with respect to being combined with the `initSolution`.

## V. MITIGATION STRATEGY

Given noisy volumes, the Modified Clique-Finding algorithm described in the previous section shows a high attack success rate (as will be shown in Section VI); that is, it finds
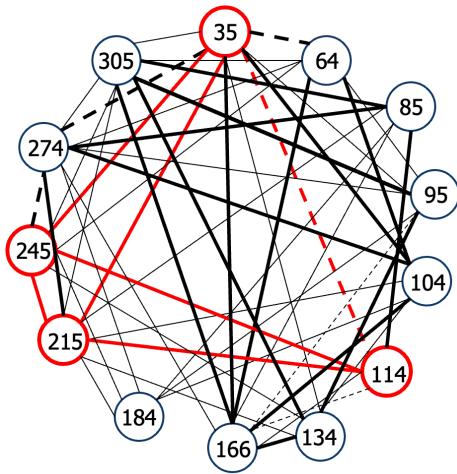
Fig. 9. A graph constructed from noisy volumes in the database
$\langle 30, 100, 80, 30, 60 \rangle$ when 6 dummy elements are added to the query
responses.

the maximum clique, finds the longest common substring to combine subsolutions, and eventually reconstructs the victim's database correctly with high probability. However, it is noted that the clique finding algorithm is an NP-Hard problem that can be only solved by checking the numbers of all cases one by one, not by polynomial solutions. The complexity of the algorithm grows quickly with the size of the range. We figure out that it works well for the ranges up to size 15 in practice. Adding a small number of nodes to a graph can significantly increase the time required to reconfigure the database; it can even cause the algorithm to fail completely. It is also important to remind that the goal of the attack is to reconstruct the volume, the size of columns on which a victim is making range queries, not exact records.

Based on the observation, this paper proposes to add noise to mitigate the reconstruction attack. Technically, dummy elements are added to results of range queries, which makes it more difficult for an attack to recover approximate volumes in the side-channel attack. The increased size of volume may create edges that should not exist or not create edges that is essential to recover a database. This directly causes the first step to find incorrect cliques; say, the size of the maximum clique found may be greater than $N$. The next step is also affected; it may fail to find the longest common substring or result in reconstructing a wrong database eventually. This approach works because the attacker is concerned only about the volume where the elements are not exposed obviously. However, regular users (i.e., victims) are not confused with the additional elements because they can access exact records in query responses and discern such elements immediately.

Back to our example of database, $\langle 30, 100, 80, 30, 60 \rangle$ in Fig.5. Remind that $\|[1,1]\| = 30$, $\|[2,2]\| = 100$, $\|[3,3]\| = 80$, $\|[4,4]\| = 30$, $\|[5,5]\| = 60$, and a set of possible values for the volume of range queries $V$ is {30, 60, 80, 90, 100, 110, 130, 170, 180, 210, 240, 270, 300}. Now, suppose that 6 dummy elements are added to the response of each range query. Then, $\|[1,1]\| = 36$, $\|[2,2]\| = 106$, $\|[3,3]\| = 86$, $\|[4,4]\| = 36$, $\|[5,5]\| = 66$, and $V = \{36, 66, 86, 96, 106, 116, 136,$

176, 186, 216, 246, 276, 306}. It is noted that $\|[1,2]\| = 136$ (= 130 + 6), not $\|[1,2]\| + \|[2,2]\| = 36 + 106 = 142$, because 6 dummy rows are being added to the result. Fig. **??** shows a graph constructed from the given volumes when 6 dummy elements are added. Comparing the edges in black to Fig. 6, it is observed that new connections are formed (solid bold lines) and some connections are missing (dotted bold lines). The edges in red correspond to the clique found in Fig. 7. It is observed that a connection between node 35 and node 114 (a dotted red line) is not formed and thus the clique is not found in the algorithm. Missing one clique implies that we lose a string information (a contiguous list of volumes) in it, which hiders from finding `lcList` and eventually leads to the failure of the combining step. The algorithm may find another clique and successfully reconstruct a database, but it must be far from the original database.

## VI. EXPERIMENTS AND RESULTS

This section performs experiments for four sets in total and shows their results. The first two sets (I and II) are the cases where an attacker launches a cache side-channel attack to measure approximate noisy volumes and then performs database reconstruction to recover a victim's database. In experiment I, distribution over all the possible queries are uniform; that is, each range are queried with equal probability. Experiment II performs non-uniform range queries. Although each range must be queried at minimum number of times, the query distribution do not need to be uniform. For this, `rand()` function is used in our system. The rest of settings are the same for I and II. In the rest two sets (III and IV), our countermeasure strategy is applied with different percentages of additional dummy elements and with different query distributions. With results, we assess their effects on the database reconstruction attack.

### A. Preliminary

For experiments, this paper uses the Nationwide Inpatient Sample (NIS) 2008 dataset [26]. The NIS is part of the Healthcare Cost and Utilization Project (HCUP) used to analyze national trends in healthcare. This data is collected annually and it has approximately 5 to 8 million hospitalization records. Since data is in an SPSS file format, we use IBM SPSS Statistics [27] to read it. Then, 10 SQLite database is created by selecting 10,000 records randomly out of 8 million ones. We perform range queries on the AMONTH element, an "admission month coded from (1) January to (12) December" (refer to [26] for the full description of elements). The list of ranges are $[1, 1], [1, 2], \ldots [1, 12], [2, 1], [2, 2], \ldots [12, 11], [12, 12]$ and possible values in the range are $N = 12$. For the non-uniform range queries, ranges $[i, j]$ are set by randomly selecting $i$ and $j$ in $1 \le i, j \le 12$. For each set, experiments are repeated 10 times and average values are returned.

We run experiments on a desktop computer with Intel Core i5-9400F CPU @ 2.90 GHz running Ubuntu 16.04. The capacities of the L1, L2, and L3 caches are 384 KB, 1.5 MB, and 9 MB, respectively. For a database engine, we use the SQLite Amalgamation version 3.20.1 with a single large file of C-code named `sqlite3.c` [28]. Table II summarizes information of our setup. We found in a heuristic manner that when approximately 120 measurements are collected for

TABLE II. Setup Information for Experiments

| Dataset | NIS 2008 database [26] |
|---|---|
| Noise budget | 0.002 |
| Possible values in the range | 12 |
| Total number of records | 10,000 |
| Capacities (L1, L2, L3) | 384KB, 1.5MB, 9MB |

TABLE III. Results (Success Rate and Error Rate) from Experiments I and II

| | Exp. I | Exp. II |
|---|---|---|
| Success rate [%] | 100 % | 100 % |
| Error rate [%] | 0.4-0.7 % | 0.2-0.7 % |

a range query, the aggregated measurements in the cache side-channel show a peak regarding the approximate volume. Because there are 78 different range queries for our data, around 10,000 traces are collected first to see if the traces for each range are sufficient so that we can check a peak for each approximate volume.

### B. Database Reconstruction from Noisy Volumes

For Experiments I and II, this paper collects 10,000 traces corresponding to 10,000 range queries; that is, 1 trace for each query. It then processes all of those traces to get a set of approximate, noisy volumes, with which the Modified Clique-Finding algorithm and the Match-Extension algorithm are performed. This returns an output of reconstructed database. The former algorithm runs with different values for the noise budget, whereas the latter algorithm is with a fixed value 0.002 of noise budget. For each value in $1, 2, \ldots, 12$, it is expected to recover a candidate volume that corresponds to the number of records in the database using that value.

For a database of size $N$, a *success rate* is defined as the number of candidate volumes recovered out of $N$. For instance, if our method recovers 10 candidate values in our experiments with the range of size $N = 12$, the success rate is $\left(\frac{10}{12}\right) \times 100$ [%]. It is noted that an attacker can distinguish between successful and unsuccessful attacks because he knows $N$, the size of the database that needs to be recovered. We also define an *error rate* of a recovered volume. For each candidate volume $\tilde{v}$ recovered, we compare it to the corresponding value $v$ in the actual database and report the error rate of $\left(\frac{|\tilde{v}-v|}{v}\right) \times 100$ [%]. For example, if the actual volume is 1,000 and the recovered volume is 980, then the error rate is reported as 0.2%. If our database reconstruction recovers 10 values out of 12, error rates only for the recovered 10 values are reported.

From experiments, it is observed that increasing a noise budget increases the average error rate and the confidence interval for the Modified Clique-Finding algorithm. For noise budgets of 0.005, some of the databases recovered in Experiment I were very far from the true database, resulting in much larger error intervals. In short, increasing the noise budget seems to have helped increase the success rate, but as the error rate increases, the quality of the recovered database decreases. It is also noted that its average running time increases with the size of the noise budget. In the case of the Match-Extension algorithm, the average error and the width of the error interval are similar to those in the Modified Clique-Finding algorithm. But, it achieves much higher success rate with a small noise budget. Experiments in this paper fix the noise budget of 0.002 and thus the average running time remains low. The Modified Clique-Finding algorithm with a noise budget of 0.006 shows better success rate than with a smaller noise budget, and is selected as an algorithm

comparable to the Match-Extension algorithm. For Experiment II, this paper performed non-uniform range queries and used the same sets of database as in Experiment I. As mentioned earlier, we need approximately 120 measurements for a range query to detect approximate, noisy volumes from the cache side-channel. This do not require that the query distribution be uniform. Technically, this experiment tests an hypothesis that the success of a database reconstruction attack relies on the capability of identifying peaks corresponding to the volumes of range queries. In this sense, a query distribution in which a peak disappears as its neighboring peaks dominate it could be challenging to attackers. One setting for the challenging distribution, for instance, is that a range [a, b] is queried more often than a range [c, d] when two ranges have close volumes (i.e., close peaks). Our random setting generate this distribution with probability, given requirement that each query be observed at least 120 times.

Table III shows our results from Experiments I and II. For Experimental I with uniform distribution for all queries, it was possible to reconstruct all 10 databases with the error rate of up to 0.7%, which is considerable in accuracy. Even in the case of Experiment II, where the query range was not uniform, we succeeded in reconstructing 10 databases correctly. The error rate was also within 0.7%. It can be seen that our database reconstruction attack has 100% success rate with low error.

### C. Database Reconstruction with Dummy Data

For Experiments III and IV, our method adds dummy data to response volumes returned by range queries. The rest of settings are same to those in Experiments I and II. Experiment III and IV perform uniform and non-uniform range queries, respectively and use approximate, noisy volumes. The database used in the experiment has 10,000 rows, and the range of the AMONTH attribute is 1 to 12. Thus, there are about 800 rows in each range. In the first setting, our method adds 8 dummies (rows) to the response of each range query. That is, it corresponds to 1% of total volumes.

Table IV shows our results from Experiments III and IV. In both experiments, 6 out of 10 databases (60%) were successfully reconstructed, and the error rate in the reconstructed databases was 9%-15%. They are comparable to results, 100% and 0.7%, in previous experiments in Table III. It is reminded that the success criterion for reconstruction is that all 12 candidate values is recovered. 60% of recovery, therefore, is far from the success of an attack. In order to investigate the impact of dummy data further, we add 2% of dummy data out of total volumes in the second setting. Table V shows its results. In both experiments, no database was reconstructed at all. This is mainly attributed to the fact that the database construction attack primarily relies on the volume size of query responses. It is so sensitive to the size that small inclusion of dummy can even weaken its success rate.

TABLE IV. RESULTS (SUCCESS RATE AND ERROR RATE) FROM EXPERIMENTS III AND IV (1% OF DUMMY)

|  | Exp. III | Exp. IV |
|---|---|---|
| Success rate [%] | 60% | 60% |
| Error rate [%] | 10-14% | 9-15% |

TABLE V. RESULTS (SUCCESS RATE AND ERROR RATE) FROM EXPERIMENTS III AND IV (2% OF DUMMY)

|  | Exp. III | Exp. IV |
|---|---|---|
| Success rate [%] | 0% | 0% |
| Error rate [%] | - | - |

## VII. CONCLUSION AND DISCUSSION

This paper investigated the impact of side-channels on open-source database engines. We triggered a side-channel attack on a cache shared by victim VMs and a spy VM using SQLite to obtain approximate, noisy volumes of the database. Two algorithms that extended a clique finding algorithm were introduced in order to perform a database reconstruction attack. This paper also introduced a mitigation method that added additional dummy data to results of range queries. Experiments were conducted with a database of 10,000 records and with 12 ranges for queries. Results showed that the database reconstruction attack could recover almost 100% volumes of the database with maximum error rate of 0.7%. With 1% of additional dummy data, however, only 60% of database were recovered with up to 15% of error rate. When adding 2% of dummy data, no database was constructed at all; the database construction attack was completely failed.

As a future work, it would be interesting to investigate the impact of the volume of dummy data further. Given the number of records (10,000) used in our experiment, the size of the volume for each range query is about 800. 1% of additional data represents 8 records only, which does not seem to be a problem. But, as the size of the database increases, this volume also increases. This will naturally increase the processing time of query requests and use a lot of memory. It is necessary to find solutions to defend against attacks without performance degradation in large scale database settings. It would be also interested to examine our models on a scenario where victim VMs and a spy VM do not share a library with a more generic form of cache side-channel attack [6].

## ACKNOWLEDGMENT

## REFERENCES

[1] "Cloud Services," https://www.datamation.com/cloud-computing/slideshows/.

[2] K. Lewi and D. J. Wu, "Order-Revealing Encryption: New Constructions, Applications, and Lower Bounds," in *ACM SIGSAC Conference on Computer and Communications Security (CCS)*, October 2016, pp. 1167–1178.

[3] R. A. Popa, C. M. Redfield, N. Zeldovich, and H. Balakri, "CryptDB: protecting confidentiality with encrypted query processing," in *ACM Symposium on Operating Systems Principles*, October 2011, pp. 85–100.

[4] "Cache side-channel attack," https://en.wikipedia.org/wiki/Side-channel_attack#cache_side-channel_attack.

[5] Y. Tsunoo, E. Tsujihara, K. Minematsu, and H. Hiyauchi, "Cryptanalysis of Block Ciphers Implemented on Computers with Cache," in *ISITA*, October 2002.

[6] D. A. Osvik, A. Shamir, and E. Tromer, "Cache Attacks and Countermeasures: the Case of AES," in *Cryptographers' Track at the RSA conference*. Springer Berlin Heidelberg, February 2006, pp. 1–20.

[7] O. Aciiçmez, "Yet another MicroArchitectural Attack:: exploiting I-Cache," in *ACM workshop on Computer security architecture*, November 2007, pp. 11—18.

[8] T. Ristenpart, E. Tromer, H. Shacham, and S. Savage, "Hey, You, Get Off of My Cloud: Exploring Information Leakage in Third-Party Compute Clouds," in *ACM conference on Computer and communications security*, November 2009, pp. 199—212.

[9] Y. Yarom and K. Falkner, "FLUSH+RELOAD: A High Resolution, Low Noise, L3 Cache Side-Channel Attack," in *USENIX Security Symposium*, August 2014, pp. 719–732.

[10] Y. Yarom and N. Benger, "Recovering openssl ecdsa nonces using the flush+reload cache side-channel attack," Cryptology ePrint Archive, 2014. [Online]. Available: https://eprint.iacr.org/2014/140

[11] A. Moghimi, G. Irazoqui, and T. Eisenbarth, "CacheZoom: How SGX Amplifies the Power of Cache Attacks," in *International Conference on Cryptographic Hardware and Embedded Systems*, August 2017, pp. 69–90.

[12] A. C, R. P. Giri, and B. Menezes, "Highly Efficient Algorithms for AES Key Retrieval in Cache Access Attacks," in *IEEE European Symposium on Security and Privacy*, March 2016, pp. 261–275.

[13] G. Irazoqui, M. S. Inci, T. Eisenbarth, and B. Sunar, "Wait a Minute! A fast, Cross-VM Attack on AES," in *International Workshop on Recent Advances in Intrusion Detection*, September 2014, p. 299–319.

[14] M. S. Inci, B. Gulmezoglu, G. Irazoqui, T. Eisenbarth, and B. Sunar, "Cache Attacks Enable Bulk Key Recovery on the Cloud," in *International Conference on Cryptographic Hardware and Embedded Systems*, August 2016.

[15] M. Y. C. W. Fletcher and J. Torrellas, "Cache Telepathy: Leveraging Shared Resource Attacks to Learn DNN Architectures," in *USENIX Security Symposium*, August 2020, pp. 2003–2020.

[16] S. Hong, M. Davinroy, Y. Kaya, S. N. Locke, I. Rackow, K. Kulda, and D. D.-S. andand Tudor Dumitras, "Security Analysis of Deep Neural Networks Operating in the Presence of Cache Side-Channel Attacks," 2018. [Online]. Available: https://arxiv.org/abs/1810.03487

[17] G. Kellaris, G. Kollios, K. Nissim, and A. O'Neill, "Generic Attacks on Secure Outsourced Databases," in *ACM SIGSAC Conference on Computer and Communications Security*, October 2016, p. 1329–1340.

[18] M.-S. Lacharité, B. Minaud, and K. G. Paterson, "Improved Reconstruction Attacks on Encrypted Data Using Range Query Leakage," in *IEEE Symposium on Security and Privacy*, May 2018.

[19] P. Grubbs, M.-S. Lacharité, B. Minaud, and K. G. Paterson, "Pump up the Volume: Practical Database Reconstruction from Volume Leakage on Range Queries," in *ACM SIGSAC Conference on Computer and Communications Security (CCS)*, October 2018, pp. 315—331.

[20] A. Shahverdi, M. Shirinov, and D. Dachman-Soled, "Database Reconstruction from Noisy Volumes: A Cache Side-Channel Attack on SQLite," in *USENIX Security Symposium (USENIX Security)*, August 2021, pp. 1019–1035.

[21] M. Naveed, S. Kamara, and C. V. Wright, "Inference Attacks on Property-Preserving Encrypted Databases," in *ACM SIGSAC Conference on Computer and Communications Security*, October 2015, p. 644–655.

[22] E. M. Kornaropoulos, C. Papamanthou, and R. Tamassia, "Data Recovery on Encrypted Databases with k-Nearest Neighbor Query Leakage," in *IEEE Symposium on Security and Privacy*, May 2019, pp. 1033–1050.

[23] ——, "The State of the Uniform: Attacks on Encrypted Databases Beyond the Uniform Query Distribution," in *IEEE Symposium on Security and Privacy*, May 2020, pp. 1223–1240.

[24] "Mastik: A Micro-Architectural Side-Channel Toolkit," https://github.com/0xADE1A1DE/Mastik.

[25] "SQLite," https://www.sqlite.org/.

[26] "Introduction to the HCUP Nationwide Inpatient Sample (NIS) 2008," https://hcup-us.ahrq.gov/db/nation/nis/NIS_Introduction_2008.jsp.

[27] "IBM SPSS Statistics," https://www.ibm.com/products/spss-statistics.

[28] "The SQLite Amalgamation," https://www.sqlite.org/amalgamation.html.

# An Approach for Classification of Diseases on Leaves

Quy Thanh Lu
Information Technology Department
FPT University
Can Tho, Viet Nam

*Abstract*—In recent years, significant advancements have been made in the realm of plant disease classification, with a particular focus on leveraging the capabilities of deep learning techniques. This study delves into the utilization of renowned Convolutional Neural Network (CNN) models, including EfficientNetB5, MobileNet, ResNet50, InceptionV3, and VGG16, for the purpose of plant disease classification. The core methodology involves employing transfer learning, wherein these established CNN models are employed as a foundation and subsequently fine-tuned using a publicly accessible plant disease dataset. The study also compared the results with some deep learning models and with state-of-the-art. Among the tested CNNs, EfficientNetB5 has shown the best performance. EfficientNetB5 has outperformed another model and obtained 99.2% classification accuracy.

*Keywords*—*Classification of diseases on leaves; transfer learning; fine-tuning; image classification; deep learning*

## I. INTRODUCTION

Plant diseases are a pervasive and complex aspect of agriculture and horticulture, exerting significant impacts on global food production and ecosystem health. Plant diseases can manifest in various ways, from visible symptoms like wilting, discoloration, and lesions to more subtle signs of stunted growth and reduced yield. The management of plant diseases necessitates a multifaceted approach, combining practices such as crop rotation, the use of disease-resistant cultivars, proper sanitation, and judicious application of pesticides. As the world grapples with the challenge of feeding a growing population, understanding and mitigating plant diseases is of paramount importance to ensure sustainable agricultural systems and safeguard global food security [1].

Hence, numerous studies in this field have been conducted, deploying various methods such as classical machine learning models and state-of-the-art deep learning techniques [2] [3] [4] [5]. Authors have also employed data preprocessing methods to enhance model accuracy. Besides, there have been studies focusing on feature extraction using traditional techniques like SURF [6], HOG [7], etc.

In this study, we used a CNN [8] model, including EfficientNetB5, MobileNet, ResNet50, InceptionV3, and VGG16, to classify plant diseases within an existing dataset. Additionally, the study compared the results with other deep learning models and state-of-the-art methods. The obtained results were highly satisfactory, achieving an accuracy and F1-score of 99.2% and 99.22%, respectively.

This article is divided into five sections. The first section is the introduction. In the subsequent Section II, we present related works. Moving forward, Section III is the proposed methodology. The experimental procedures and outcomes are discussed in Section IV. Lastly, the conclusion wraps up the article.

## II. RELATED WORKS

Numerous research have been conducted in recent years to address the issue of plant disease. Researchers are continuously finding new, creative ways to increase their accuracy.

In the article [9], the author proposed a deep learning-based method for tomato disease detection that utilizes the Conditional Generative Adversarial Network (C-GAN) to generate synthetic images of tomato plant leaves. Then, a DenseNet121 model is trained on synthetic and real images using transfer learning to classify the tomato leaves images into ten categories of diseases. The results obtained accuracy of 99.51%, 98.65%, and 97.11% for tomato leaf image classification into five classes, 7 classes, and 10 classes, respectively.

In [10], a comprehensive four-step procedure is presented for enhancing the accuracy of plant disease detection and classification in images. The process commences with pre-processing, employing a Wiener filter to mitigate background noise. Disease spots are subsequently identified using the hue histogram in the HIS model, followed by precise segmentation through the K-means algorithm and highest hue value calculation in the HSV color model. Afterward, seventeen color and texture features are extracted from the disease-affected regions and input into a forward-propagation deep neural network (FPDNN) classifier. To improve results, the Bayesian regularization back propagation algorithm is applied. Impressively, the FPDNN was subjected to testing with varying hidden layers, achieving its peak accuracy of 97.18% with 19 hidden layers. This underscores the effectiveness of this methodology in accurate plant disease identification and classification.

In [11], the authors concentrated their efforts on crafting an integrated model for the precise detection of tomato diseases through the utilization of image data. To achieve this, they rigorously assessed the performance of seven distinct neural network architectures, including renowned ones like VGG16, ResNet50, and various EfficientNet variants, all fine-tuned through transfer learning methodologies. After a thorough evaluation, the most proficient models were selected, and a weighted average ensemble technique was applied to amalgamate them. This amalgamation resulted in the proposal of a final model boasting an impressive accuracy rate of 98.1%.

This study [12], the identified diseases were categorized into three distinct groups: bacterial, viral, and fungal infections. The research delved into a thorough exploration of these aspects and employed a range of machine learning (ML) and deep learning (DL) techniques. The ML methods employed in the study encompassed SVM, KNN, RF (Random Forest), and LR (Logistic Regression), while the DL approach featured the use of Convolutional Neural Networks (CNN) for disease prediction in plants. Among the machine learning classifiers, the RF (Random Forest) yielded the highest accuracy, achieving an impressive rate of 97.12%. However, the CNN classifier, representing the deep learning model, outshone them all with an even higher accuracy of 98.43%.

In the study [13] conducted by Nagamani H S and Sarojadevi H, the focus was directed towards the detection and classification of diseases that impact tomato leaves, employing a range of machine learning techniques. This comprehensive investigation encompassed the utilization of FuzzySVM, Convolutional Neural Network (CNN), and Region-based Convolutional Neural Network (R-CNN) models. The researchers executed an array of sophisticated image processing and feature extraction methodologies to enhance the predictive capabilities of their models. Remarkably, their findings unveiled that the R-CNN model emerged as the standout performer, achieving an impressive accuracy rate of 96.735% in the classification of various disease types afflicting tomato plants.

In research [14] of Nishant Garg and colleagues , the model was meticulously trained on a substantial dataset consisting of 8,000 images across the relevant classes and rigorously tested on a separate test set comprising 2,000 images. The hybrid methodology employed a fusion of Convolutional Neural Network (CNN) for effective feature extraction from input data and a finely tuned Support Vector Machine (SVM) classifier for precise classification. This synergistic combination proved to be highly effective, achieving an impressive accuracy rate of 92.6%. The authors, in [15], used a Convolutional Neural Network (CNN), specifically the VGG model, to detect Multi-Crops Leaf Disease (MCLD) by classifying diseased and healthy crop leaves. They achieved impressive results with an accuracy of 98.40% for grapes and 95.71% for tomatoes.

In their research paper [16], the authors conducted a comprehensive assessment of deep learning techniques, leveraging pre-trained CNN models within the PyTorch framework for the classification of tomato plant diseases. They evaluated various models, such as EfficientNetB0, ResNext-50-32x4d, and MobileNet-V2, with ResNext-50-32x4d emerging as the top performer, achieving an impressive accuracy rate of 90.14%. In the paper cited as [17], the authors introduce a novel approach for classifying seven distinct types of tomato diseases employing Deep Learning models. Their models were trained on an extensive dataset comprising 10,448 images, and the results were striking. The trained models exhibited remarkable accuracy, with the highest testing precision achieving an impressive 95.71%.

This article [18] used deep learning for crop disease detection. They employed a Convolutional Neural Network (CNN) with two convolutional and two pooling layers in the model. The results are quite promising, as the proposed CNN model outperformed well-known pre-trained models like InceptionV3, ResNet 152, and VGG19. The CNN achieved an impressive 98% training accuracy and maintained a strong 88.17% testing accuracy. This paper [19] focuses on the identification of tomato plant diseases, utilizing a transfer learning approach with the EfficientNetB3 model. The dataset comprises 11 distinct types of leaves and is sourced from an online database. The EfficientNetB3 model undergoes 15 training iterations with a batch size of 32, employing two optimizers, Adamax and Adam. Notably, the use of the Adam optimizer resulted in an accuracy of 94%.

In this research [20], a prediction model for Tomato Early Blight Disease (TEBD) was developed using image-based data. The TEBD dataset was improved through various image processing techniques such as Background Removal, Augmentation, Resizing, Noise Removal, and Segmentation. Subsequently, a Convolutional Neural Network (CNN) was employed to train the model on the enhanced dataset. The model's performance was exceptional, achieving a remarkable mean accuracy of 98.10%, demonstrating its capacity to accurately predict TEBD with a batch size of 64 and 15 training epochs.

In the study described in [21], the researchers employed established CNN architectures like AlexNet, ResNet50, and VGG16 for feature extraction. Subsequently, they applied the minimum redundancy maximum relevance feature selection algorithm to refine these features for optimal performance. These selected features were then combined through concatenation. To classify the concatenated features, the researchers utilized well-known machine learning classification algorithms. Remarkably, their proposed approach achieved outstanding results, boasting an impressive accuracy of 98.3% for tomato leaf disease detection and 96.3% for the Taiwan dataset.

In this study [22], an innovative approach was introduced by fusing two pre-trained models, namely EfficientNetB3 and MobileNet, collectively referred to as the EffiMob-Net model, for highly precise tomato leaf disease detection. The researchers conducted thorough hyperparameter tuning to meticulously select the ideal settings for constructing the most suitable model. The performance of this hybrid model was rigorously assessed, focusing on accuracy metrics specifically chosen for disease detection. Impressively, the proposed EffiMob-Net model achieved an exceptional success rate of 99.92%. In reference [23], the research leveraged pre-trained CNN models, namely Inception V3 and Inception ResNet V2, to effectively classify images of tomato leaves as healthy or unhealthy. Remarkably, their approach yielded outstanding results, boasting a remarkable accuracy rate of 99.22%. Additionally, they managed to keep the loss to an impressively low 0.03. This achievement was made possible through strategic use of dropout rates, with 50% for one model and 15% for the other.

In [24], authors employed a dataset comprising tomato leaves, encompassing six distinct disease types along with a class for healthy tomato leaves. This dataset, consisting of 6,594 tomato leaf images, was sourced from Plant Village. In addtional, approach of study, utilizing the ResNet-50 model, delivered a remarkable outcome, achieving a substantial accuracy rate of 96.35% when tested on a balanced dataset split, with 50% used for training and the remaining 50% for testing. In this study [25], Sanjeela Sagar and Jaswinder Singh conducted an experimental and comparative analysis of

tomato leaf disease classification, employing both traditional machine learning algorithms such as random forest (RF), support vector machines (SVM), and naïve bayes (NB), as well as a deep learning convolutional neural network (CNN) algorithm. Notably, our findings revealed that the CNN, specifically when integrated with a pre-trained Inception v3 model, outperformed traditional methods. This advanced approach achieved an impressive accuracy rate of over 95%.

In [26], Irene Sultana and her team have introduced a substantial dataset consisting of 14,529 tomato leaf images encompassing ten distinct infections. In their study, they harnessed the power of deep learning by employing InceptionV3 and ResNet-50 as the learning algorithms, capitalizing on transfer learning techniques for classifier training. Their innovative deep learning model delivered commendable outcomes, achieving an accuracy rate of 85.52% for InceptionV3 and an even more impressive 95.41% for ResNet-50. In this research paper [27], authors focus on the crucial task of cassava plant disease detection, recognizing that deep learning models surpass traditional machine learning methods, as observed in prior research. In additional, Prashant Giridhar Shambharkar and Saurabh Sharma employ the EfficientNet-B0 architecture in conjunction with k-fold cross-validation to develop a highly effective disease detection model. EfficientNet's reputation for superior classification, speed, and scalability across various dimensions makes it an ideal choice. Result attains an impressive 96.68% accuracy when evaluated on a collect Kaggle dataset.

The common challenge for researchers is the difficulty in increase accuracy to classification of plant diseases on leaves. Therefore, in this study, we have conducted several experiments on several Machine Learning models (including pre-trained Deep Learning models) to validate their better performance in the scenario.

## III. BACKGROUND

### A. Image Classification

One of the most pivotal and burgeoning research domains in contemporary times is image classification, particularly within the realm of medical imaging analysis. Image classification, also referred to as image categorization, plays a critical role in determining the presence of diseases by generating a classification output based on input images. Its primary objective is to assign a specific label to an image, which proves instrumental in various applications.

Image classification extends its relevance to numerous real-world sectors and industries, encompassing environmental studies, agriculture, remote sensing, urban planning, surveillance systems, geographic mapping, disaster management, and item identification. This versatile and transformative technology not only aids in medical diagnoses but also finds widespread utility in addressing a multitude of challenges and opportunities across diverse fields.

### B. Convolutional Neural Network (CNN)

Convolutional Neural Networks (CNNs) stand as a cornerstone in the domain of deep learning, particularly in the realm of image analysis and recognition [8]. CNNs leverage a distinctive mathematical technique known as convolution,

which involves performing an operation on two functions to derive a third function, illustrating the transformation of one function by the other. In CNN architecture, convolution plays a pivotal role in extracting hierarchical features from input images, enabling the network to progressively discern complex patterns. CNNs are composed of multiple layers of artificial neurons, which function as mathematical units responsible for aggregating input information and generating activation values, closely mirroring the information processing capabilities of human neurons, as they assimilate sensory inputs and produce corresponding responses. This structural and functional alignment with biological neural systems contributes to CNNs' extraordinary efficacy in tackling intricate image-based tasks and solidifies their status as a cornerstone technology in modern deep learning.

Kernel convolution [8] serves as a foundational element not only in Convolutional Neural Networks (CNNs) but also in various Computer Vision methodologies. This technique involves the application of a small matrix, referred to as the kernel or filter, to modify an image based on the filter's values. In the context of the mathematical representation, the input image is symbolized as $g$ and the kernel is represented as $p$. The process can be expressed using the following formula, which is instrumental in generating subsequent feature map values. The indices for the rows and columns of the resulting matrix are typically denoted as $a$ and $b$, respectively, as indicated in equation (Eq. 1). This fundamental operation forms the basis for extracting important visual information and features from images, underpinning a wide range of computer vision applications.

$$G[a,b] = (g*p)[a,b] = \sum_i \sum_j p[i,j]g[a-i,b-j] \quad (1)$$

Within the Convolutional Neural Network (CNN) architecture, the first layer is the convolutional layer, tasked with the process of disentangling diverse features from the input images. In this layer, a $NxN$ sized filter is employed in tandem with the input image to execute the convolution operation. The forward propagation through this layer unfolds in two phases. Initially, the first step is to determine the intermediate value $X$, which is produced when the input data from the previous layer is convolutioned with the $Y$ tensor (which contains filters), and then bias $d$ is added. The next involves using our intermediate value as the input for a non-linear activation function (our activation is denoted by $h$). For the fans of matrix equations, the subsequent formulas, encapsulated as Eq. (2) and (3).

$$X^{[l]} = Y^{[l]}.C^{[l-1]} + d^{[l]} \quad (2)$$

$$C^{[l]} = h^{[l]}(X^{[l]}) \quad (3)$$

### C. ResNet50 Model

ResNet [28] represents a distinctive variant of a convolutional neural network (CNN) that was first presented in the research paper titled "Deep Residual Learning for Image Recognition" in 2015. This concept is introduced by He Kaiming, Zhang Xiangyu, Ren Shaoqing, and Sun Jian. ResNet-50 is a convolutional neural network that is 50 layers deep, including

48 convolutional layers, one MaxPool layer, and one average pool layer. Residual neural networks are a type of artificial neural network (ANN) that constructs networks by assembling residual blocks [29].

### D. MobileNet Model

MobileNet [30] is a simple but efficient and not very computationally intensive convolutional neural networks for mobile vision applications. MobileNet is widely used in many real-world applications which includes object detection, fine-grained classifications, face attributes, and localization. In this lecture, I will explain you the overview of MobileNet and how exactly it becomes the most efficient and lightweight neural network. MobileNet uses depthwise separable convolutions. It significantly reduces the number of parameters when compared to the network with regular convolutions with the same depth in the nets. This results in lightweight deep neural networks.

### E. VGG16 Model

VGG16 [31] is a convolutional neural network model proposed by K. Simonyan and A. Zisserman from the University of Oxford in the paper "Very Deep Convolutional Networks for Large-Scale Image Recognition" [32]. The model achieves 92.7% top-5 test accuracy in ImageNet, which is a dataset of over 14 million images belonging to 1000 classes. It was one of the famous model submitted to ILSVRC-2014. It makes the improvement over AlexNet by replacing large kernel-sized filters (11 and 5 in the first and second convolutional layer, respectively) with multiple 3×3 kernel-sized filters one after another. VGG16 was trained for weeks and was using NVIDIA Titan Black GPU's.

### F. InceptionV3 Model

InceptionV3 [33] is an image recognition model that has been shown to attain greater than 78.1% accuracy on the ImageNet dataset. The model is the culmination of many ideas developed by multiple researchers over the years. It has a total of 42 layers and a lower error rate than its predecessors. Additional, it is introduced on the original paper: "Rethinking the Inception Architecture for Computer Vision" by Szegedy, et. al. [34].

### G. EfficientNetB5 Model

EfficientNetB5 [35] is part of a family of eight DCNN models called EfficientNet, introduced by Google AI [36]. The eight models of EfficientNet range from B0 to B7 where the largest is B7. EfficientNets showed higher accuracy and better efficiency in comparison to existing CNNs. The EfficientNet architectures are based on a scaling approach that uses a compound coefficient to consistently scale the three dimensions (resolution, depth, and width). This results in higher performance and greater accuracy of the models.

### IV. PROPOSED ARCHITECTURE

Fig. 1 shows our proposed approach. The goal of this process is to increase the amount of data large enough for deep learning models to bring high efficiency to the model. Then, the data will be divided into three parts: training set,

validating set and testing set. Next, pretrain models with the ImageNet dataset are used without the output layer. We reuse all the trained weights from the ImageNet dataset. After input layer, we create an additional layer called AugmentedLayer, this layer is responsible for enhancing data from the input dataset with different techniques such as: flip, rotation, zoom and contract. After that, we proceed to add layers in turn: Dense with 256 hidden units, followed by activation layer with ReLu, Batch Normalization layer, dropout layer with value 0.3, dense layer and final is output layer.
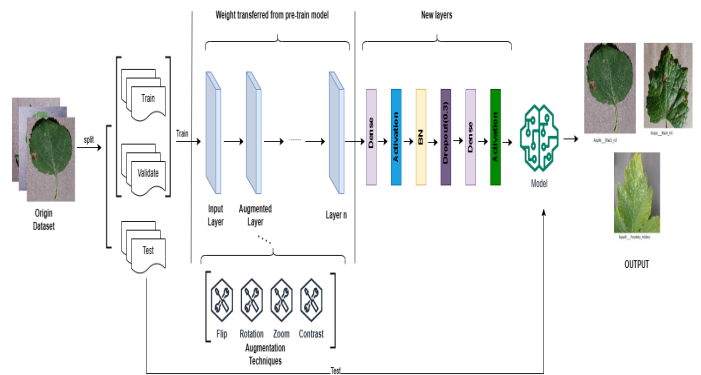


Fig. 1. Our proposed architecture.

The details of the input and output of each layer and the number of parameters of the proposed architecture are shown in Table I.

TABLE I. SUMMARY OF PROPOSED MODELS

| Layer (type) | Output Shape | Param # |
|---|---|---|
| inputLayer (InputLayer) | [(None, 224, 224, 3)] | 0 |
| AugmentationLayer (Sequential) | (None, 224, 224, 3) | 0 |
| efficientnetb5 (Functional) | (None, 2048) | 28513527 |
| dense_3 (Dense) | (None, 256) | 524544 |
| activation_1 (Activation) | (None, 256) | 0 |
| batch_normalization_1 (BatchNormalization) | (None, 256) | 1024 |
| dropout_1 (Dropout) | (None, 256) | 0 |
| dense_4 (Dense) | (None, 38) | 9766 |
| activationLayer (Activation) | (None, 38) | 0 |
| ... | | |
| Trainable params: 534,822 | | |
| Non-trainable params: 28,514,039 | | |

### V. EXPERIMENTS

### A. Dataset and Experimental Environment

The dataset [37] used contained 87,867 images of fruits and vegetables belonging to 38 different categories. The pre-split data consists of three sets: training, validation and testing. The training set includes 70,295 images. The validation set has 15,814 images. The test set contains 1,758 images. Each photo will contain a plant-diseases of leaves. Fig. 2 shows the distribution of data of the training set.

In this experimental, we train the data with the proposed model. The experiment was performed on a computer with the following configuration: Core i5 12400F, 32GB RAM, and Geforce RTX 3060 12VRAM graphics card.
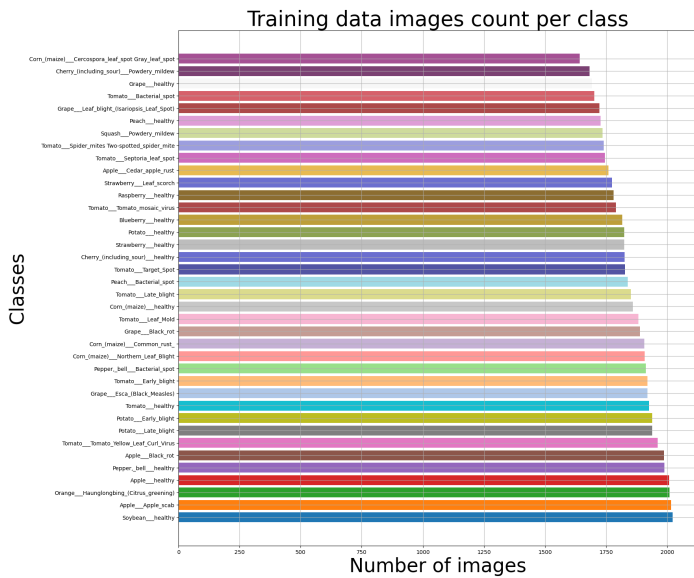
Fig. 2. Data distribution.
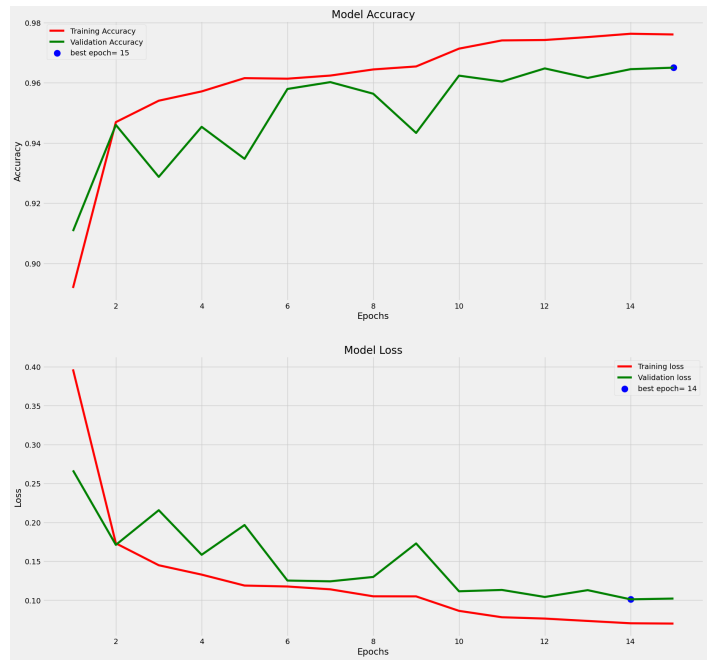


Fig. 3. Accuracy and loss during training.

### B. Experiment 1: Evaluation of the Proposed Model

In this experiment, we performed on the hyperparameter set with the specified values as follows: batch_size=32, epoch=15, learning_rate=0.00001, and optimizer=Adam. The Table II compares the results between some deep learning models based on our approach. In which, (1) is train loss, (2) is train accuracy, (3) is validation loss, (4) is validation accuracy, (5) is test loss, (6) is test accuracy and final is F1-Score.

TABLE II. COMPARISON BETWEEN THE PROPOSED MODEL AND SOME OTHER MODELS

| Models | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
|---|---|---|---|---|---|---|---|
| **EfficientNetB5** | **0.22** | **0.92** | **0.14** | **0.95** | **0.02** | **0.992** | **0.992** |
| InceptionV3 | 1.70 | 0.50 | 1.92 | 0.45 | 1.35 | 0.587 | 0.585 |
| MobileNet | 0.65 | 0.79 | 0.67 | 0.78 | 0.57 | 0.82 | 0.82 |
| ResNet50 | 0.06 | 0.97 | 0.10 | 0.96 | 0.03 | 0.9898 | 0.9898 |
| VGG16 | 0.24 | 0.91 | 0.21 | 0.92 | 0.06 | 0.9829 | 0.9829 |

From the comparison table above, we can see that the fine-tune EfficientNetB5 model achieves a performance of 99.2 with both accuracy and F1 measure. Fig. 3 shows the accuracy and loss in training data of it.

And the confusion matrix of the fine-tune EfficientNetB5 model is shown in Fig. 4.

### C. Experiment 2: Compare the Results with Some other Deep Learning Models and State-of-the-Art

In Experiment 2, to have a basis for evaluating the effectiveness of the proposed approach, we also compare the results of the proposed model (*fine-tuned EfficientNetB5 model with highest accuracy in Experiment 1*) with the state-of-the-arts. The results are shown in the Table III.

From the results in Table II and Table III, we can see that our approach is quite simple but achieves high effectiveness in the applied classification problem. With a large amount of image data (87,867 images) combined with augmented layer,
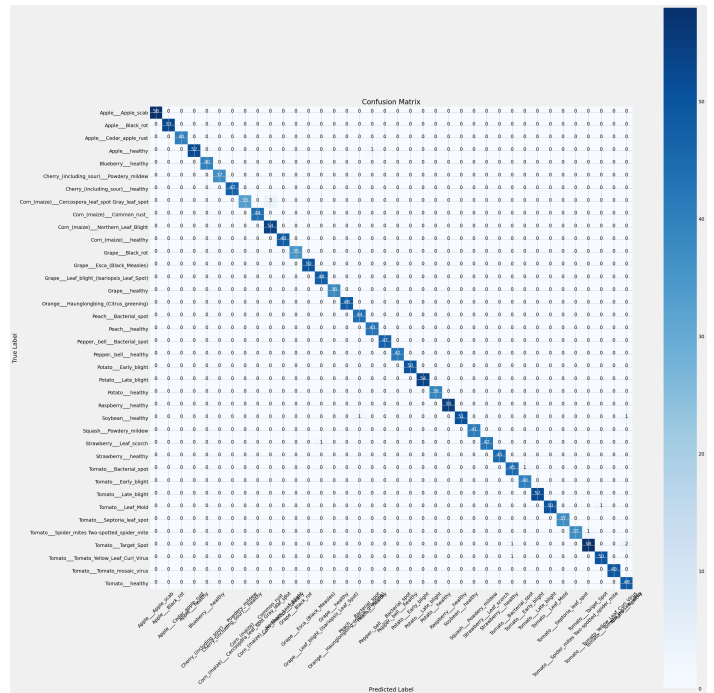


Fig. 4. Confusion matrix of fine-tuned efficientNetB5 model.

this study demonstrates superiority over most other models. However, in some cases, it is not as effective as [22] and [23].

## VI. CONCLUSION

The problem of plant disease classification based on images plays a significant role in real-life scenarios, particularly in contributing to addressing issues related to the quality and quantity of agricultural produce. The results of research on leaf

TABLE III. COMPARISON WITH STATE-OF-THE-ARTS

| Refs | Dataset | No. Classes | No. Images | Accuracy |
|------|---------|-------------|------------|----------|
| [9] | tomato plantvillage | 5 | 16,012 | 0.971 - 0.995 |
| [22] | Plantvillage | 11 | 32,535 | 0.9992 |
| [10] | plant village | 19 | 75 | 0.9718 |
| [11] | plant village tomato leaf | 10 | 14500 | 0.981 |
| [12] | plant village | 30 | 53200 | 0.9843 |
| [16] | plantvillage | 38 | 163,000 | 0.9014 |
| [13] | tomato leaf disease | 7 | 735 | 0.96735 |
| [17] | Plantvillage | 7 | 11,165 | 0.9571 |
| [18] | Plantvillage | 14 | 3,000 | 0.98 |
| [23] | Plantvillage | 14 | 54,305 | 0.9922 |
| [24] | Plantvillage | 6 | 6,594 | 0.9635 |
| [14] | tomato leaf disease | 8 | 10000 | 0.926 |
| [15] | plantvillage | 38 | 54,303 | 0.984 |
| [25] | Plantvillage | 5 | 11,123 | 0.95 |
| [26] | Plantvillage | 10 | 14,529 | 0.9541 |
| [27] | Cassava disease leaf | 5 | 22,031 | 0.9668 |
| **Ours** | **Plant Disease** | **38** | **87,867** | **0.992** |

disease classification also aid in more accurate identification of various diseases affecting plants. In the realm of plant disease classification, numerous studies have explored various methodologies, including classical machine learning models, deep learning models, transfer learning, and fine-tuning techniques. However, the results have not yet been obtained really high such as: the number of plant disease leaves in the data set is small or the accuracy achieved is not high. Because of that, this study has proposed an approach through building a CNN model that is relatively simple but helps bring about high accuracy. The study tested on a data set of 38 classes of plant disease leaves. The results are very satisfactory with the accuracy and F1-Score of 99.2% and 99.22%, respectively. In the future, we will build new models or combine from many different models to further improve the accuracy of this problem.

## REFERENCES

[1] D. M. Rizzo, M. Lichtveld, J. A. K. Mazet, E. Togami, and S. A. Miller, "Plant health and its effects on food safety and security in a one health framework: four case studies," in *One Health Outlook 3 (2021)*, 2021.

[2] Y. Zhang and L. Wu, "Classification of fruits using computer vision and a multiclass support vector machine," *Sensors*, vol. 12, no. 9, pp. 12 489–12 505, 2012. [Online]. Available: https://www.mdpi.com/1424-8220/12/9/12489

[3] S. Wang, Y. Zhang, G. Ji, J. Yang, J. Wu, and L. Wei, "Fruit classification by wavelet-entropy and feedforward neural network trained by fitness-scaled chaotic abc and biogeography-based optimization," *Entropy*, vol. 17, no. 8, pp. 5711–5728, 2015. [Online]. Available: https://www.mdpi.com/1099-4300/17/8/5711

[4] K. V. Hong, T. T. Minh, H. L. Duc, N. T. Nhat, and H. L. Hoang, "104 fruits classification using transfer learning and densenet201 fine-tuning," in *Complex, Intelligent and Software Intensive Systems*, L. Barolli, Ed. Cham: Springer International Publishing, 2022, pp. 160–170.

[5] G. Zeng, "Fruit and vegetables classification system using image saliency and convolutional neural network," in *2017 IEEE 3rd Information Technology and Mechatronics Engineering Conference (ITOEC)*, 2017, pp. 613–617.

[6] H. Bay, T. Tuytelaars, and L. Van Gool, "Surf: Speeded up robust features," in *Computer Vision – ECCV 2006*, A. Leonardis, H. Bischof, and A. Pinz, Eds. Berlin, Heidelberg: Springer Berlin Heidelberg, 2006, pp. 404–417.

[7] N. Dalal and B. Triggs, "Histograms of oriented gradients for human detection," in *2005 IEEE Computer Society Conference on Computer Vision and Pattern Recognition (CVPR'05)*, vol. 1, 2005, pp. 886–893 vol. 1.

[8] K. O'Shea and R. Nash, "An introduction to convolutional neural networks," 2015.

[9] A. Abbas, S. Jain, M. Gour, and S. Vankudothu, "Tomato plant disease detection using transfer learning with c-gan synthetic images," in *Computers and Electronics in Agriculture*, vol. 187, 2021.

[10] V. K. Trivedi, P. Shukla, and A. Pandey, "Plant leaves disease classification using bayesian regularization back propagation deep neural network," in *CONference on Smart and Intelligent Learning for Information Optimization (CONSILIO)-2021*, 2021.

[11] M. Moussafir, H. Chaibi, R. Saadane, A. C. amd Abdessamad El Rharras, and G. Jeon, "Design of efficient techniques for tomato leaf disease detection using genetic algorithmbased and deep neural networks," in *Plant and Soil - An International Journal on Plant-Soil Relationships*, vol. 479, 2022, p. 251–266.

[12] M. Kirola, K. Joshi, S. Chaudhary, N. Singh, H. Anandaram, and A. Gupta, "Plants diseases prediction framework: A image-based system using deep learning," in *IEEE World Conference on Applied Intelligence and Computing (AIC) 2022*, 2022, pp. 307–313.

[13] N. H. S and S. H, "Tomato leaf disease detection using deep learning techniques," in *International Journal of Advanced Computer Science and Applications (IJACSA)*, vol. 13, 2022.

[14] N. Garg, R. Gupta, M. Kaur, V. Kukreja, A. Jain, and R. G. Tiwari, "Classification of tomato diseases using hybrid model (cnn-svm)," in *2022 10th International Conference on Reliability, Infocom Technologies and Optimization (Trends and Future Directions) (ICRITO)*, 2022.

[15] A. S. Paymode and V. B. Malode, "Transfer learning for multi-crop leaf disease image classification using convolutional neural network vgg," in *Artificial Intelligence in Agriculture*, 2022.

[16] R. Lohith, K. E. Cholachgudda, and R. C. Biradar, "Pytorch implementation and assessment of pre-trained convolutional neural networks for tomato leaf disease classification," in *2022 IEEE Region 10 Symposium (TENSYMP)*, 2022.

[17] M. Abdulla and A. Marhoon, "Design a mobile application to detect tomato plant diseases based on deep learning," in *Bulletin of Electrical Engineering and Informatics*, 2022.

[18] G. Sakkarvarthi, G. W. Sathianesan, V. S. Murugan, A. J. Reddy, P. Jayagopal, and M. Elsisi, "Detection and classification of tomato crop disease using convolutional neural network," in *Electronics*, 2022.

[19] R. Singh, A. Sharma, V. Anand, and R. Gupta, "Impact of efficientnetb3 for stratification of tomato leaves disease," in *2022 6th International Conference on Electronics, Communication and Aerospace Technology*, 2022.

[20] N. Sareen, A. Chug, and A. P. Singh, "An image based prediction system for early blight disease in tomato plants using deep learning algorithm," in *Journal of Information and Optimization Sciences*, vol. 43, 2022.

[21] E. Cengil and A. Çınar, "Hybrid convolutional neural network based classification of bacterial, viral, and fungal diseases on tomato leaf images," in *Concurrency and Computation Practice and Experience*, vol. 34, 2022.

[22] Z. Ullah, N. Alsubaie, M. Jamjoom, S. H. Alajmani, and F. Saleem, "Effimob-net: A deep learning-based hybrid model for detection and identification of tomato diseases using leaf images," in *Big Data Analytics and Machine Learning for Smart Agriculture*, no. 13(3), 737, 2023.

[23] A. Saeed, A. A. Abdel-Aziz, A. Mossad, M. A. Abdelhamid, A. Y. Alkhaled, and M. Mayhoub, "Smart detection of tomato leaf diseases using transfer learning-based convolutional neural networks," in *agriculture*, no. 13(1), 139, 2023.

[24] S. Kumar, S. Pal, V. P. Singh, and P. Jaiswal, "Performance evaluation of resnet model for classification of tomato plant disease," in *Epidemiologic Methods*, vol. 12, 2023.

[25] S. Sagar and J. Singh, "An experimental study of tomato viral leaf diseases detection using machine learning classification techniques," in *Bulletin of Electrical Engineering and Informatics*, 2023, pp. 451–461.

[26] I. Sultana, B. Paul, A. Mahmud, M. M. Rafi, M. A. Jishan, and K. R. Mahmud, "Automatic recognition and categorization of tomato leaf syndrome of diseases using deep learning algorithms," in *Information and Communication Technology for Competitive Strategies (ICTCS 2022)*, 2023, pp. 43–54.

[27] P. G. Shambharkar and S. Sharma, "Plant disease detection and prevention using deep learning," in *2023 9th International Conference on Advanced Computing and Communication Systems (ICACCS)*, 2023.

[28] K. He, X. Zhang, S. Ren, and J. Sun, "Deep residual learning for image recognition," 2015.

[29] Datagen, "Resnet-50: The basics and a quick tutorial," 2023. [Online]. Available: https://datagen.tech/guides/computer-vision/resnet-50

[30] A. G. Howard, M. Zhu, B. Chen, D. Kalenichenko, W. Wang, T. Weyand, M. Andreetto, and H. Adam, "Mobilenets: Efficient convolutional neural networks for mobile vision applications," 2017.

[31] K. Simonyan and A. Zisserman, "Very deep convolutional networks for large-scale image recognition," 2015.

[32] ——, "Computer vision and pattern recognition," in *Very Deep Convolutional Networks for Large-Scale Image Recognition*, 2015.

[33] C. Szegedy, V. Vanhoucke, S. Ioffe, J. Shlens, and Z. Wojna, "Rethinking the inception architecture for computer vision," 2015.

[34] ——, "Computer vision and pattern recognition," in *Rethinking the Inception Architecture for Computer Vision*, 2015.

[35] M. Tan and Q. V. Le, "Efficientnet: Rethinking model scaling for convolutional neural networks," 2020.

[36] ——, "International conference on machine learning," in *EfficientNet: Rethinking Model Scaling for Convolutional Neural Networks*, 2019.

[37] S. BHATTARAI, "New plant diseases dataset," 2023. [Online]. Available: https://www.kaggle.com/datasets/vipoooool/new-plant-diseases-dataset

# Transformer-based End-to-End Object Detection in Aerial Images

Nguyen D. Vo, Nguyen Le, Giang Ngo, Du Doan, Do Le, Khang Nguyen*
University of Information Technology, Ho Chi Minh City, Vietnam
Vietnam National University, Ho Chi Minh City, Vietnam

*Abstract*—Transformer models have achieved significant milestones in the field of Artificial Intelligence in recent years, primarily focusing on text processing and natural language processing. However, the application of these models in the domain of image processing, particularly on aerial images data, is actively research. This study concentrates on the experimental evaluation of Transformer-based models such as DETR, DAB-DETR, and DINO on the challenging Visdrone dataset, which is also essential for aerial image data processing. The experimental results indicate that Transformer-based models exhibit substantial potential, especially in object detection on aerial image data. Nevertheless, their application is not without challenges, including low resolution, dense object occurrences, and environmental noise. This work provides an initial glimpse into both the capabilities and limitations of Transformer-based approaches within this domain, with the aim of stimulating further development and optimization for practical applications, including traffic monitoring, environmental protection, and various other domains.

*Keywords*—*Object detection; aerial images; end-to-end; transformer-based; DETR; DAB-DETR; DINO*

## I. Introduction

One of the foundational tasks in the computer vision field is untangling the Object Detection problem. The purpose of this task is to predict the location and classify various objects in an image, thereby fostering an enhanced understanding of visual content. This serves as a critical cornerstone for numerous computer vision applications and various practical technology domains, including healthcare, security, transportation, education, etc. In recent years, the emergence of unmanned aerial vehicles (UAVs, drones, and flycams) has resulted in a surge of aerial data, presenting abundance of advantageous opportunities that conventional sources cannot provide, such as diverse perspectives and panoramic views (Fig. 1). Successfully tackling this task holds significant potential for enhancing and broadening intelligent applications like security monitoring or smart transportation. Hence, object recognition in aerial image data is a subject of paramount importance and a vigorously researched area. However, this task presents a myriad of challenges, including but not limited to small object dimensions, high object densities, and low image resolutions [1], [2].

Research on object detection in recent years can be categorized into three major divisions: two-stage methods, known for their high accuracy, with Faster R-CNN [3] serving as a representative example; one-stage methods, with YOLO [4] algorithm as a prominent representative, known for its fast

inference time; and end-to-end methods. End-to-end methods have gained popularity within the research community in recent years due to their simplicity, efficiency, ease of integration, utilization of global information, and time and cost savings during setup and training phases (see Fig. 2). For these reasons, conducting research on end-to-end methods for object detection is essential to enhance performance and facilitate their integration into real-world applications in the field of computer vision [5].

An abundance of end-to-end methods have been proposed to address object detection, including several Transformer-based end-to-end models, such as DETR [6], DAB-DETR [7], and DINO [8]. These methods are evaluated on general objects across standard datasets, such as Pascal VOC [9] and MS-COCO [10]. Each method has its own strengths and weaknesses. In contrast, there is still a limitation in evaluation of these methods in the aerial data domain. Exploring and analyzing the advantages and disadvantages of end-to-end methods promises to provide valuable information for future research.

Therefore, this study focuses on surveying and analyzing three representative end-to-end models, namely DETR [6], DAB-DETR [7], and DINO [8]. Experiments are conducted on standard aerial image datasets VisDrone2019 [11]. Challenges in the aerial image data domain will be highlighted and discussed, along with potential approaches to address the difficulties encountered by these models.

The remaining part of the paper is organized as follows: In Section II, we present related research. Three Transformer-based end-to-end object detection methods, including DETR, DAB-DETR, and DINO, will be described in Section III. The detailed experimental results of the Transformer-based end-to-end method on the VisDrone dataset are reported and discussed in Section IV, along with provided evaluations. Finally, Section V will conclude this paper and suggest directions for future research.

## II. Related Works

Object detection represents a foundational task within the field of computer vision, requiring the precise classification and localization of objects of interest within both images and video content.This task holds an essential position in a variety of practical applications, ranging from traditional utilizations like image annotation to modern applications such as autonomous vehicles, robots, surveillance systems, and augmented reality [12]. Over the past decade, object detection methods based on deep learning have garnered significant

*Corresponding author
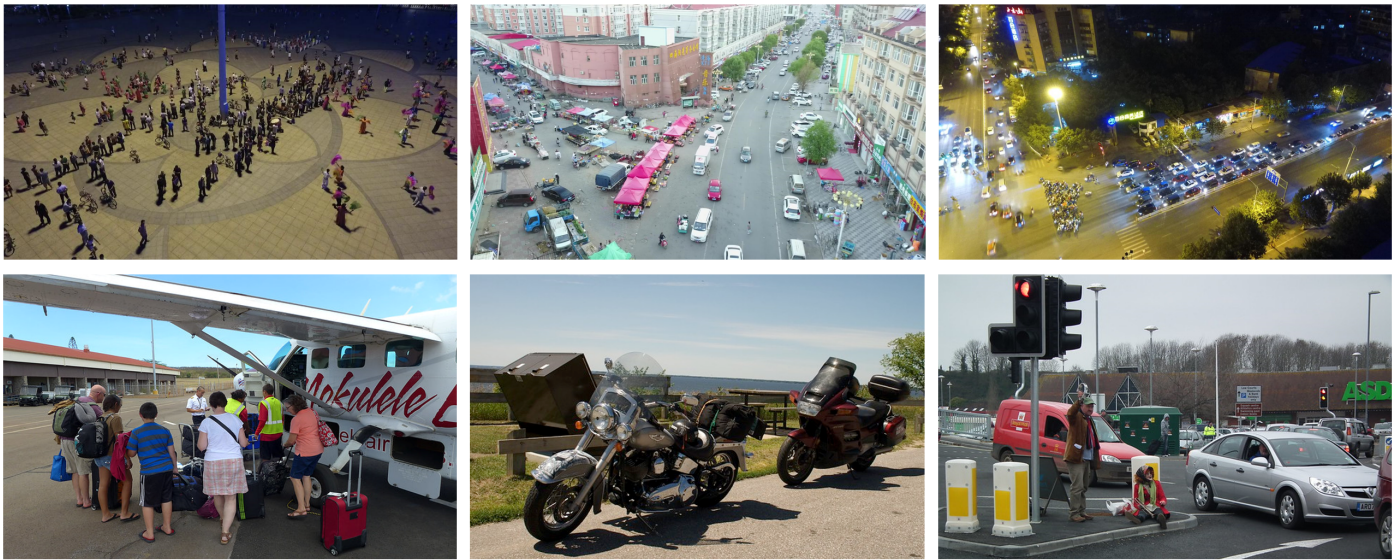
Fig. 1. Images acquired from ground-level vantage points (below) and those obtained from aerial perspectives (above) provide a comparison in terms of perspective and scope. Aerial images (above) offer a wide field of view, encompassing diverse angles and densely distributed small objects. Ground-captured images (below) showcase finer details and focus on more distinct objects.

attention due to the rapid advancements in deep learning techniques [13]. However, there are still a substantial number of challenges, including balancing accuracy and efficiency, handling multi-scale objects, and developing lightweight models.

Traditional object detection methods have primarily relied on convolutional neural networks (CNNs), including Faster R-CNN [3], SSD [14], and YOLO [4]. Some YOLO-based methods, including PH-YOLOv5 [15], AVS-YOLO [16], YOLOv7-Drone [17], and so on, have been specifically developed for object detection in aerial images. Leveraging the considerable success of Transformer in natural language processing (NLP), researchers have been striving to apply Transformer architectures to computer vision tasks. As a result, an extensive number of vision models based on Transformer have emerged in recent years, achieving comparable or even superior performance compared to CNN-based variants.

Transformer architecture [18], which were initially proposed as a self-attention mechanism for machine translation tasks, have increasingly gained attention in object detection, especially in the last three years. High-performance models such as DETR [6], DAB-DETR [7], DINO [8], and many others have been proposed. Currently, Transformer-based models have become a novel approach to object detection, making systematic analysis and evaluation of these models essential for future research.

In recent years, unmanned aerial vehicles (UAVs) have been steadily developing, becoming more affordable, capable of longer flights, and highly maneuverable. Researchers leverage these advantages to employ drones in supporting various daily activities, including rapid delivery services, security surveillance, traffic monitoring, border patrols, and even military use. This has led to the generation of a vast number of images and videos, posing new challenges for object detection. While an abundance of object detection methods have been proposed and have achieved high effectiveness on common datasets like Pascal VOC [9] and MS-COCO [10], they often yield inferior results when tested on non-standard datasets, particularly in the aerial domain. This underscores the need for object detection algorithms and models capable of handling diverse object sizes, densities and viewing angles, as well as adapting to noisy images and low-resolution data resulting from remote sensing. Evaluating Transformer-based methods in the aerial domain is important, as it can provide valuable insights into the challenges of this unique data domain.

## III. METHODOLOGY

### A. DETR [6]

In two-stage object detection models, bounding boxes are estimated based on proposals using Region of Interest (RoI), while one-stage detector rely on anchors. Research has shown that the model's performance is significantly influenced by how initial predictions are generated. In mid-2020, Nicolas Carion and Francisco Massa along with other colleagues introduced a completely new approach to the object detection problem. The DETR model (Fig. 3) considers object detection as a set-based matching problem, performs detection and classification in an end-to-end pipeline harnessing the Transformer architecturea distinct paradigm when juxtaposed with one-stage modelsfor comprehensive image processing. DETR also does not generate RoIs or other intermediate steps (e.g., anchor boxes) as in two-stage models.

Two key factors that contribute to DETR's direct object detection capability are a loss function called bipartite matching loss, which ensures a unique match between predictions and ground truth; a network architecture capable of predicting sets of objects and modeling the relationships between them (Fig. 3). DETR is renowned for its revolutionary architecture that reduces the complexity of object detection while achieving strong performance in various scenarios.
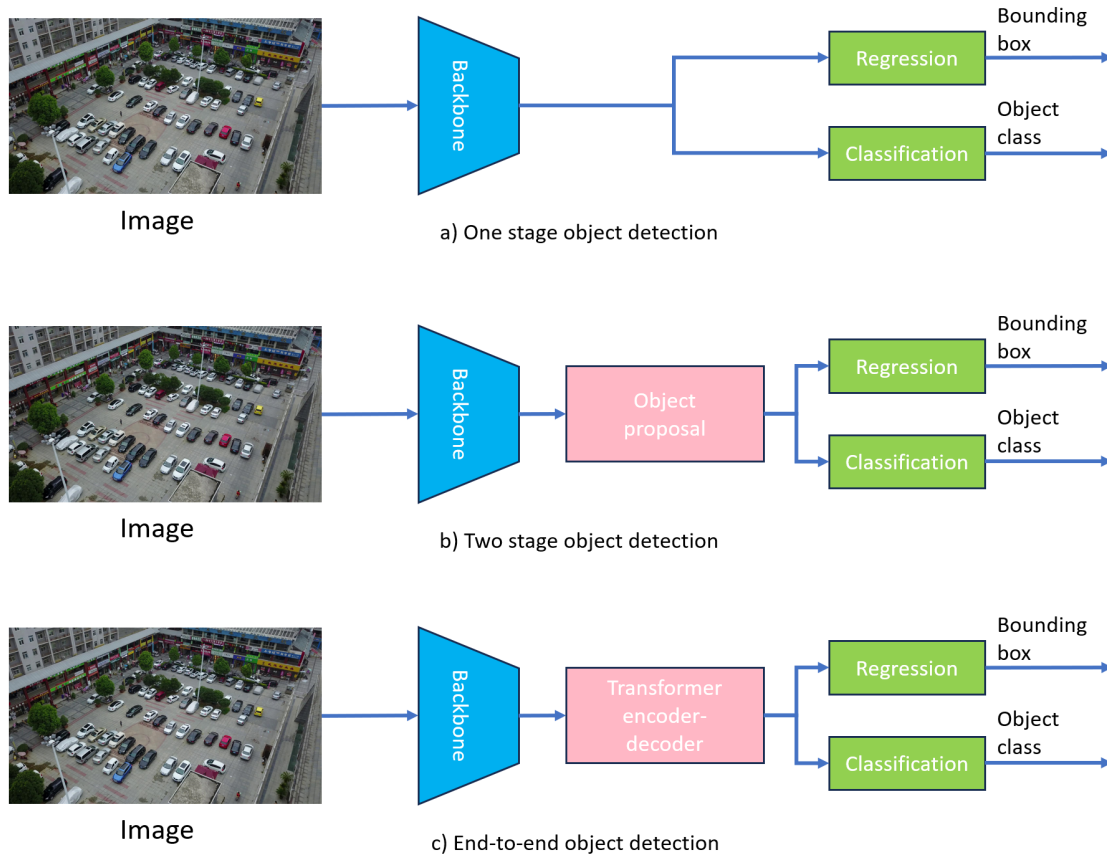
Fig. 2. The framework of the three common object detection methods. Figure a) represents a one-stage object detection model. Figure b) represents a two-stage object detection model. Figure c) represents an end-to-end object detection model.[6]

In contrast, DETR has several limitations, including slow training convergence time compared to other object detection models like Faster R-CNN and subpar performance when detecting small-sized objects. The underlying reason of these problems can be attributed to the absence of components in the Transformer architecture while processing a set of object features. Initially, the attention modules assign random weights to all pixels in the object feature set. A considerable number of epochs is necessary during the training process to allow the attention weights to be learned, focusing on important and sparse pixels [19].

### B. DAB-DETR [7]

The DAB-DETR introduces a new query formulation, which is applied within the DETR (Detection Transformer) model, aiming to enhance the understanding of the role of queries in DETR. This new query formulation directly utilizes the coordinates of bounding boxes as queries during the decoding process of the Transformer and dynamically updates them across model layers. This approach has led to significant improvements in the similarity between queries and bounding box features, simultaneously solving the slow convergence issue during DETR training. By using bounding box coordinates as queries, the authors have been able to integrate explicit location information into the querying process and adjust attention maps' positions based on the width and height information of each bounding box.

This representation allows the deployment of queries in DETR as a soft Region of Interest (ROI) aggregation and layer-wise classification stacking process. Specifically, the DAB-DETR method utilizes 4D anchor box coordinates (x, y, w, h) as queries in DETR, as shown in Fig. 4, and updates them across layers. With the information about the size of each anchor box (w, h), Gaussian positional constraints can be adapted to better fit objects of different scales. Additionally, shaping queries as anchor boxes allows for using the center position (x, y) of anchor boxes for feature extraction, increasing the similarity between queries and features and eliminating the slow convergence issue during training. This provides a simpler implementation and a deeper understanding of the role of queries in DETR.

### C. DINO [8]

Research directions stemming from DETR are increasingly receiving attention and continuously evolving. The weaknesses of DETR have been addressed and improved continuously. However, most of the improvements have been focused on individual modules and have not resulted in a significant breakthrough. DINO synthesizes prior advancements and introduces superior methods, which have led to a significant leap forward for end-to-end approaches. DINO is a model similar to DETR, with an end-to-end architecture comprising a backbone, a multi-layer Transformer encoder, a multi-layer Transformer decoder, and multiple prediction heads. The overall pipeline is
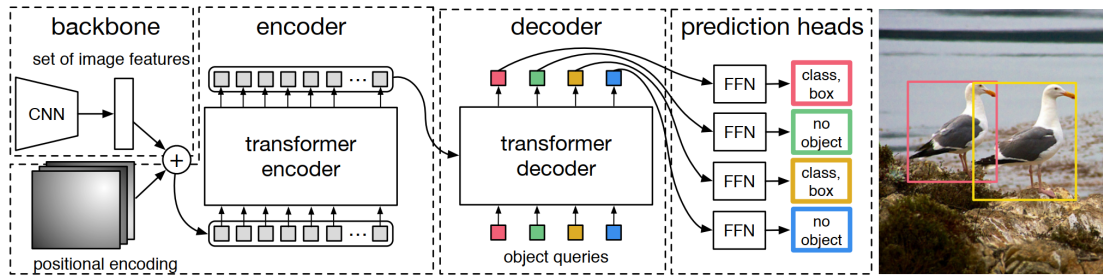
Fig. 3. The architecture of DETR consists of three main components: a CNN network serving as the backbone to extract image features, a Transformer encoder-decoder architecture, and a feed-forward network (FFN) to generate the final predictions [6].
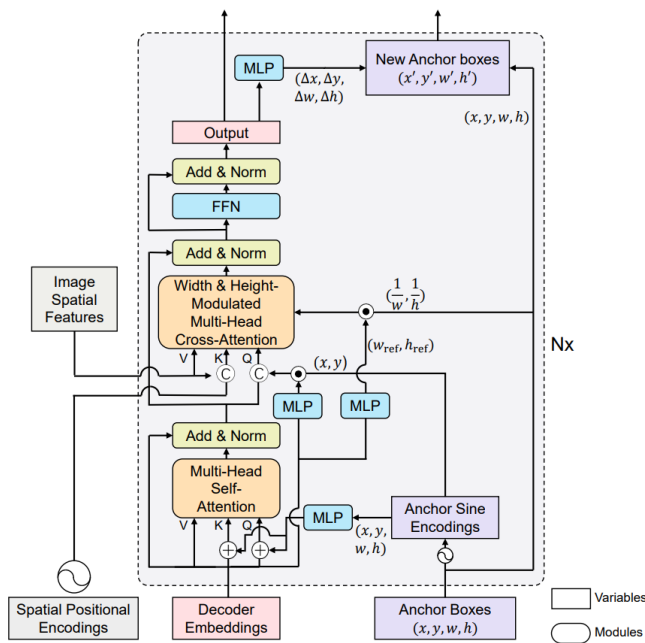


Fig. 4. DAB-DETR directly uses dynamically updated anchor boxes to provide both a reference query point (x, y) and a reference anchor size (w, h) to improve the cross-attention computation [7].

depicted in Fig. 5.

In this approach, multi-level features are extracted from input images using backbones like ResNet or Swin Transformer. These features, along with positional embeddings, are then processed through a Transformer encoder. A unique query selection strategy is introduced to initialize anchors as position queries for the decoder, while content queries are left for learning. The model utilizes these initialized anchors and learnable content-based queries in conjunction with a deformable attention mechanism to merge features from encoder outputs and update queries at each layer and stage. The ultimate output is generated from adjusted anchor boxes, and classification results are predicted using fine-tuned content features.

Just like DN-DETR, this model incorporates a denoising branch (DN) to carry out noise reduction during training. Beyond the conventional DN technique, a novel noise-contrastive reduction training method is introduced, taking into account challenging negative samples. To maximize the utilization of

information from the modified boxes in later stages, which aids in optimizing neighboring stage parameters, a unique "look forward twice" technique is introduced to facilitate the gradient propagation between adjacent layers.

## IV. RESULTS AND DISCUSSION

### A. Dataset

In this work, the VisDrone-DET (object detection in images) dataset [11] is utilized. This dataset comprises images collected through drones in various real-world scenarios, using different types of drones, across multiple locations (14 cities in China spanning thousands of kilometers), and under various weather and lighting conditions. VisDrone-DET contains a total of 8,629 images, with 6,471 for training, 1,610 for test-dev, and 548 for validation (Table I). The dataset also includes over 350,000 bounding boxes for labeled objects across 12 classes: *ignored regions, pedestrian, people, bicycle, car, van, truck, tricycle, awning-tricycle, bus, motor*, and *others*. Excluding the 2 classes, *ignored regions* and *others*, the study delves into the remaining 10 object classes. Some images of the dataset are shown in the Fig. 6

### B. Experimental Configuration

Experiments were carried out on Detrex Toolbox [20], Ubuntu 20.04.1 LTS operating system (Linux 5.8.0-53-generic x86-64), Python version 3.8.17, CUDA 11.3, PyTorch 2.0.1, and 2 NVIDIA GeForce RTX 2080 Ti GPUs. Pretrained models are employed for both the training and evaluation processes of three methods: DETR, DAB-DETR, and DINO, all utilizing the R50 backbone. The Average Precision (AP) metric introduced in MS-COCO [10] is used in the object detection process.

### C. Discussion

After training the DETR model with a ResNet-50 backbone, the best mAP result obtained was 7.64%. This data reveals that DETR struggles with objects of small or very small sizes. Table II has been presented, showcasing the AP results for each class of interest. Upon analysis, the classes *bus* (19.29%) and *car* (21.70%) achieved the highest scores. Overall, individual class scores remain limited, displaying significant variation. In comparison to other models in this study, DETR's performance on the VisDrone dataset remains notably low.
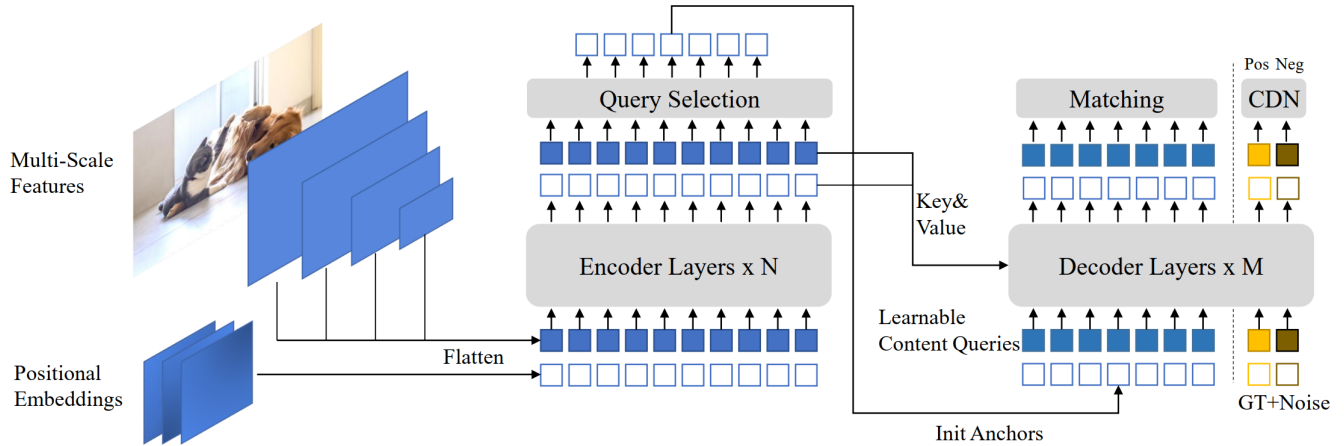
Fig. 5. Illustration of the DINO framework. The main improvements mainly focus on the Transformer encoder and Transformer decoder. The top-K encoder features in the last layer are selected to initialize query positions for the Transformer decoder, while content queries are retained as learnable parameters. The decoder also includes a DeNoising Contrastive component with both positive and negative samples [8].
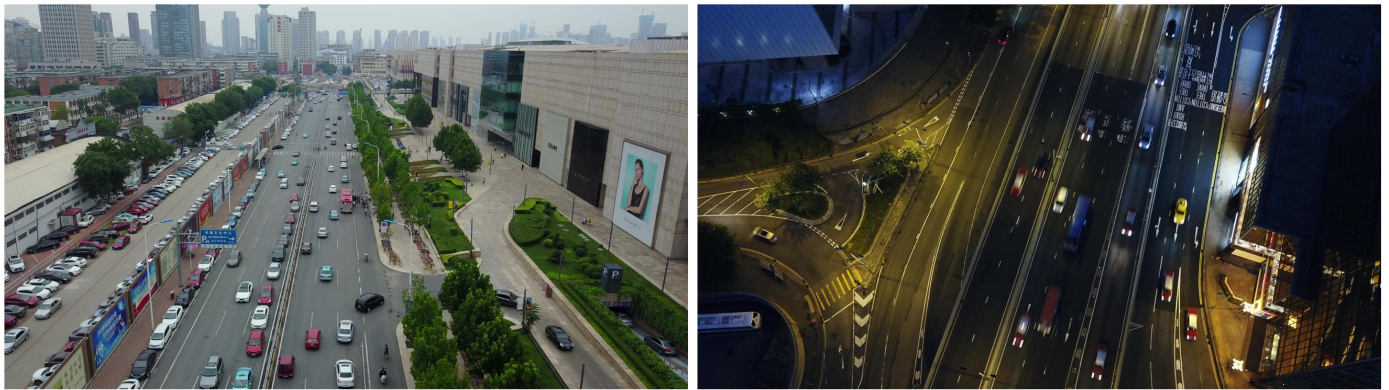


Fig. 6. Some sample images from the VisDrone dataset [11].

TABLE I. STATISTICAL INFORMATION ABOUT THE VISDRONE2019 DATASET

| Class/ Subset | Ignore | Pedestrian | People | Bicycle | Car | Van | Truck | Tricycle | Awning-tricycle | Bus | Motor | Others |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Train | 8,813 | 79,337 | 27,059 | 10,480 | 144,867 | 24,956 | 12,875 | 4,812 | 3,246 | 5,926 | 29,647 | 1,532 |
| Validation | 1,378 | 8,844 | 5,125 | 1,287 | 14,064 | 1,975 | 750 | 1,045 | 532 | 251 | 4,886 | 32 |
| Test-dev | 2,180 | 21,006 | 6,376 | 1,302 | 28,074 | 5,771 | 2,659 | 530 | 599 | 2,940 | 5,845 | 265 |
| Total | 12,371 | 109,187 | 38,560 | 13,069 | 187,005 | 32,702 | 16,284 | 6,387 | 4,377 | 9,117 | 40,378 | 1,829 |

Upon examining the AP scores for each class in DAB-DETR, it is evident that the classes *car* and *bus* attained the highest scores at 36.40 and 34.86 AP points, respectively. Interestingly, the *car* class has the highest number of labels in the training dataset, with 144,867 labels, whereas the *bus* class has significantly fewer labels, specifically 5,926 labels. However, the AP score for the *bus* class is nearly on par with that of the *car* class.

Two other classes, *van* and *truck*, also achieved relatively good AP scores, with 22.31 and 20.81 AP points, respectively. The remaining classes, including *motor, bicycle, tricycle, awning-tricycle, people* and *pedestrian*, all had AP scores less than half of those for the *car, bus, van,* and *truck* classes.

*Bicycle* and *people* had the lowest AP scores, with only 5.36 and 4.35, respectively.

According to the results presented in Table II, a prominent observation arises, demonstrating DINO's distinction as the top-performing object detector, boasting an mAP score of 24.83%. This achievement can be partly attributed to DINO's notable performance in discerning object categories characterized by resemblances, for instance, *pedestrian* and *people*, with respective scores of 15.60 and 9.38, as well as *tricycle* and *awning-tricycle*, exhibiting scores of 17.25 and 16.76, which appear relatively subdued compared to other object classes. However, it is worth noting that DINO still exhibits relatively weaker performance when compared to other popular methods,

TABLE II. THE EVALUATION RESULTS OF THE DETR, DAB-DETR, AND DINO METHODS ON THE VISDRONE DATASET USING THE AP METRIC

| Class / Method | Pedestrian | People | Bicycle | Car | Van | Truck | Tricycle | Awning-tricycle | Bus | Motor | mAP (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| DETR | 2.41 | 1.23 | 1.01 | 21.70 | 10.13 | 8.92 | 2.71 | 1.32 | 19.29 | 2.57 | 7.64 |
| DAB-DETR | 7.88 | 4.35 | 5.36 | 36.40 | 22.31 | 20.81 | 10.01 | 7.04 | 34.86 | 9.26 | 16.56 |
| DINO | 15.60 | 9.38 | 9.98 | 47.71 | 31.14 | 30.56 | 17.25 | 16.76 | 45.05 | 17.57 | 24.83 |



a. Ground truth

b. DETR
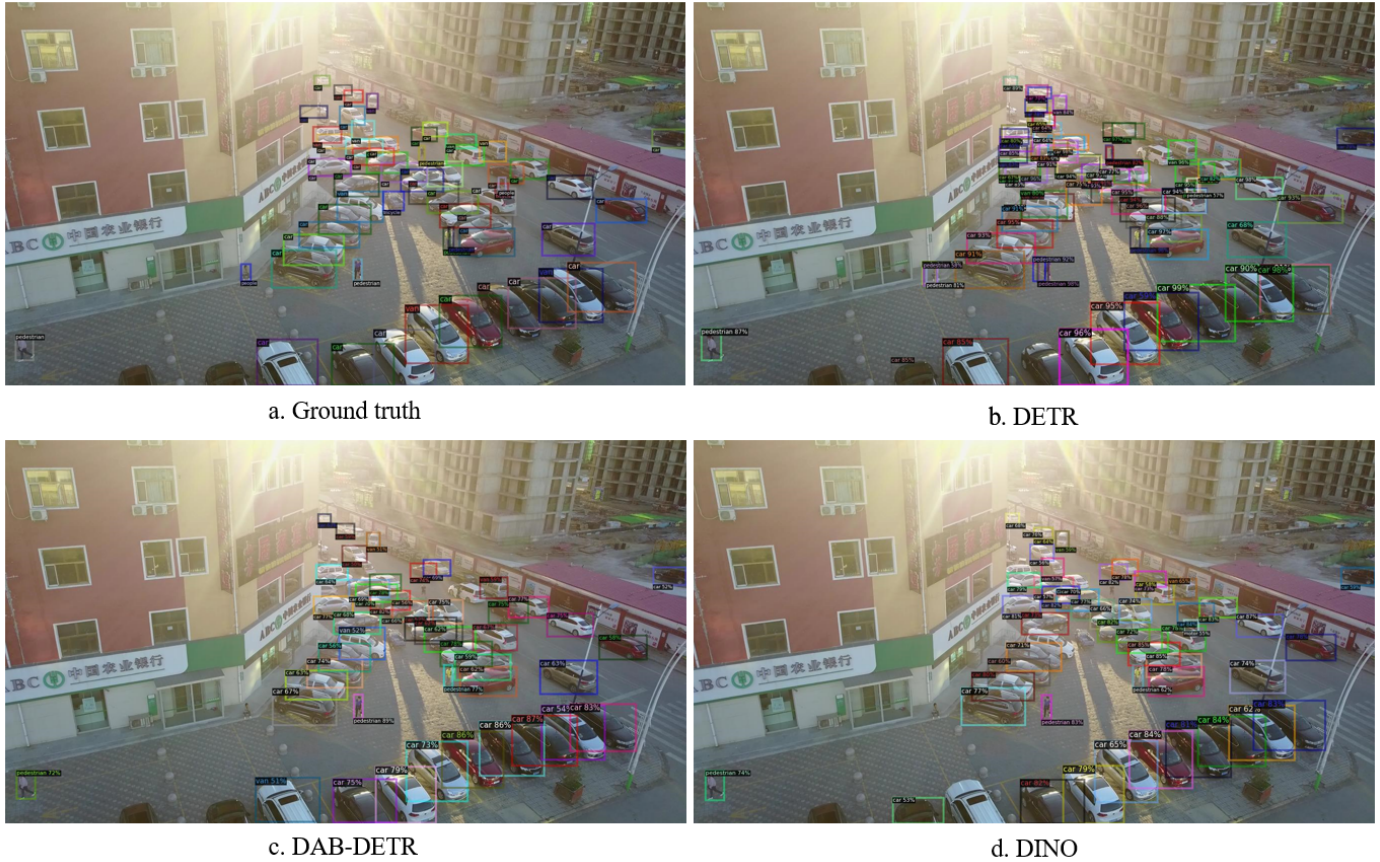
c. DAB-DETR

d. DINO

Fig. 7. Visualizing the results of the three object detection methods in challenging scenarios with occlusion and truncation.

such as YOLOv4 and YOLOv5 [1].

When using three models namely DETR, DAB-DETR, and DINO for inference on challenging images from the VisDrone dataset, each model yielded different results. Specifically, in Fig. 7, which shows a scenario with multiple small-sized, densely packed, and heavily occluded cars, the DETR model exhibited issues with multiple occlusion bounding boxes, imprecise positioning and sizing. On the other hand, the DAB-DETR and DINO models showed fewer instances of occlusion bounding boxes compared to DETR. While some objects were only detected when using a specific model, however, all three models failed to detect a partially obscured car in the distant corner.

Fig. 8 is captured in a more challenging scenario characterized by low lighting conditions, blurred and out-of-focus elements, and a higher density of both smaller and larger objects. The DETR model, while still experiencing bounding box overlap, managed to detect more objects in this context. Both DAB-DETR and DINO yielded relatively similar results,

particularly in detecting small pedestrian objects. DAB-DETR outperformed the other two models by detecting a bus object in the center of the image, which remained undetected by the other two methods. Due to the significant number of missed object detections, all three models have not yet achieved satisfactory results when confronted with blurred images, small objects, and high object density.

In Fig. 9, where the object density is not too high but the scene is considerably darker, causing objects to appear more blurred, the DETR model managed to detect most objects in the image, although a few objects were mislabeled, and there was an instance of bounding box overlap. DAB-DETR and DINO, on the other hand, detected fewer objects but provided more accurate results.

From the three examples above, it is evident that the DETR model excels in detecting more objects when images are dark and blurred. However, it faces challenges with a significant number of overlapping bounding boxes, and its accuracy in terms of bounding box size and position is not very high.

a. Ground truth

b. DETR
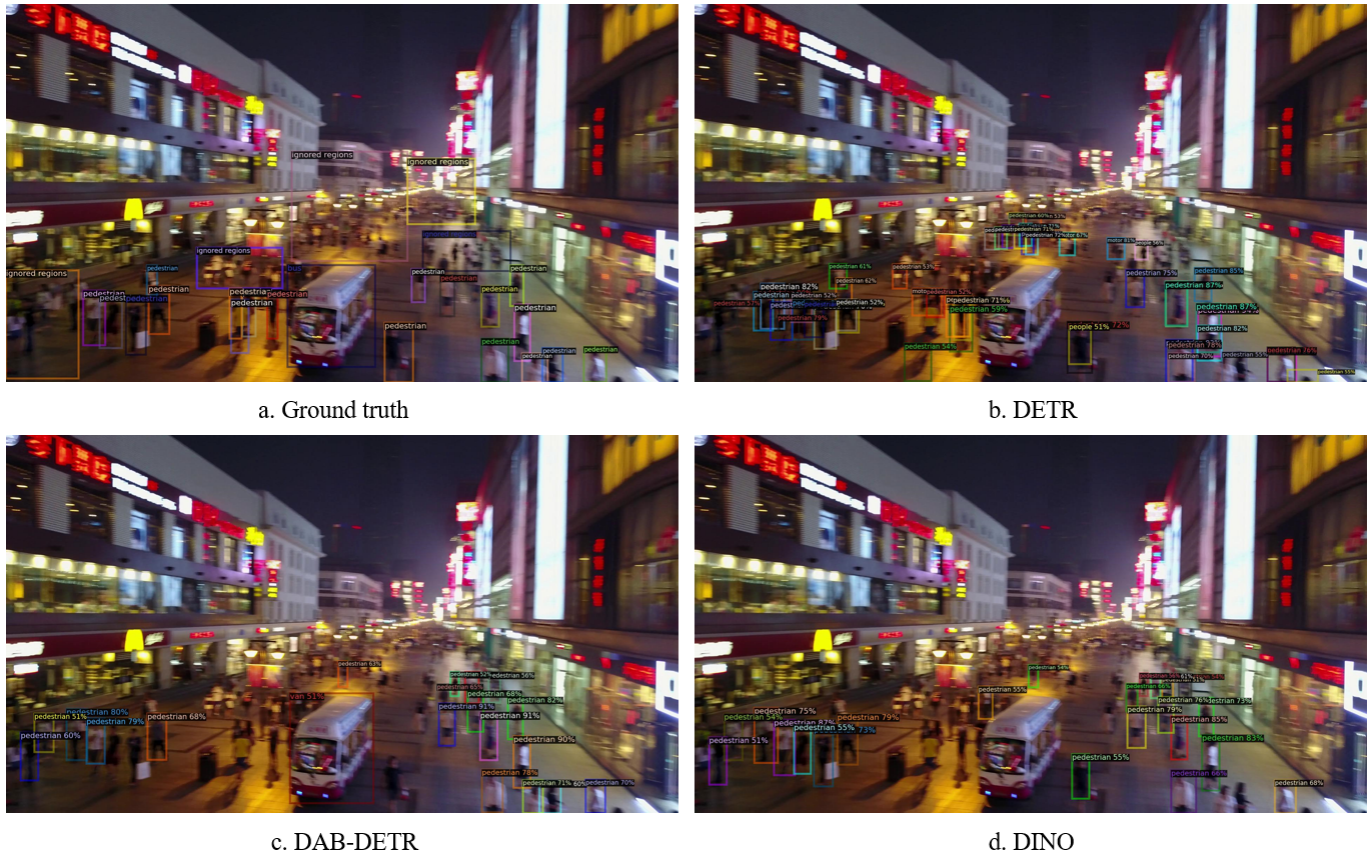
c. DAB-DETR

d. DINO

Fig. 8. Visualizing the results of the three methods for dark, blurry, and densely populated image scenarios.

This often results in mislabeling of objects. Conversely, the DAB-DETR and DINO models exhibit higher accuracy and stability. However, they are less effective when operating on dark, blurred, or fuzzy images.

## V. CONCLUSION

To offer a fresh perspective on the task of object detection in aerial image domains, we conducted experiments using three novel end-to-end object detection methods based on the Transformer architecture. These methods include DETR, DAB-DETR, and DINO, and they were evaluated on the well-known VisdroneDET2019 dataset. When using mAP as the evaluation metric, we observed that these end-to-end Transformer-based models achieved promising performance. While DETR was a pioneering method in tackling end-to-end object detection, it achieved a modest mAP score of 7.64. In contrast, DAB-DETR achieved a higher mAP score of 16.56 by employing the Dynamic Anchor Boxes technique. Specifically, the model achieving the highest mAP score among the three experimental methods is DINO, with an AP of 24.83. This is attributed to the application of several advanced techniques compared to DETR and DAB-DETR, such as Contrastive denoising training, Mixed query selection, and "Look forward twice". This is a stable and promising result for the object detection task using the end-to-end Transformer-based approach. This paper represents a crucial milestone for us to undertake more effective improvements in future research.

## REFERENCES

[1] P. Zhu, L. Wen, D. Du, X. Bian, H. Fan, Q. Hu, and H. Ling, "Detection and tracking meet drones challenge," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 44, no. 11, pp. 7380–7399, 2021.

[2] P. Nguyen, T. Truong, N. D. Vo, and K. Nguyen, "Rethinking classification of oriented object detection in aerial images," *International Journal of Advanced Computer Science and Applications*, vol. 13, no. 9, 2022.

[3] R. Girshick, "Fast r-cnn," in *Proceedings of the IEEE international conference on computer vision*, 2015, pp. 1440–1448.

[4] P. Jiang, D. Ergu, F. Liu, Y. Cai, and B. Ma, "A review of yolo algorithm developments," *Procedia Computer Science*, vol. 199, pp. 1066–1073, 2022.

[5] K. Han, Y. Wang, H. Chen, X. Chen, J. Guo, Z. Liu, Y. Tang, A. Xiao, C. Xu, Y. Xu *et al.*, "A survey on vision transformer," *IEEE transactions on pattern analysis and machine intelligence*, vol. 45, no. 1, pp. 87–110, 2022.

[6] N. Carion, F. Massa, G. Synnaeve, N. Usunier, A. Kirillov, and S. Zagoruyko, "End-to-end object detection with transformers," in *European conference on computer vision*. Springer, 2020, pp. 213–229.
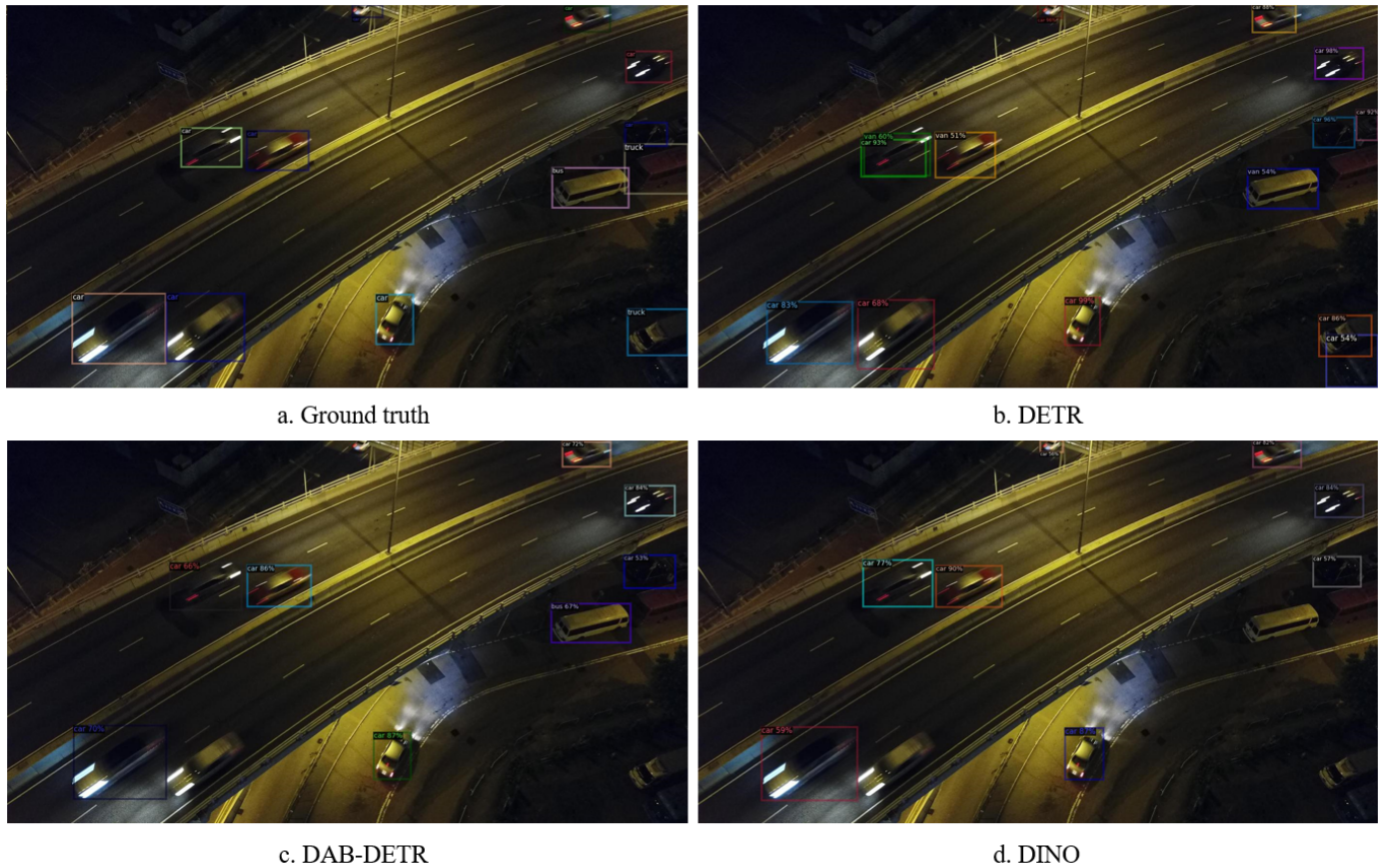
Fig. 9. Visualizing the results of the three methods in low-light, blurred, and fuzzy conditions on an overpass.

[7]   S. Liu, F. Li, H. Zhang, X. Yang, X. Qi, H. Su, J. Zhu, and L. Zhang, "Dab-detr: Dynamic anchor boxes are better queries for detr," *arXiv preprint arXiv:2201.12329*, 2022.

[8]   H. Zhang, F. Li, S. Liu, L. Zhang, H. Su, J. Zhu, L. M. Ni, and H.-Y. Shum, "Dino: Detr with improved denoising anchor boxes for end-to-end object detection," *arXiv preprint arXiv:2203.03605*, 2022.

[9]   M. Everingham, S. A. Eslami, L. Van Gool, C. K. Williams, J. Winn, and A. Zisserman, "The pascal visual object classes challenge: A retrospective," *International journal of computer vision*, vol. 111, pp. 98–136, 2015.

[10]  T.-Y. Lin, M. Maire, S. Belongie, J. Hays, P. Perona, D. Ramanan, P. Dollár, and C. L. Zitnick, "Microsoft coco: Common objects in context," in *Computer Vision–ECCV 2014: 13th European Conference, Zurich, Switzerland, September 6-12, 2014, Proceedings, Part V 13*. Springer, 2014, pp. 740–755.

[11]  D. Du, P. Zhu, L. Wen, X. Bian, H. Lin, Q. Hu, T. Peng, J. Zheng, X. Wang, Y. Zhang *et al.*, "Visdrone-det2019: The vision meets drone object detection in image challenge results," in *Proceedings of the IEEE/CVF international conference on computer vision workshops*, 2019, pp. 0–0.

[12]  K.-D. Nguyen, K. Nguyen, D.-D. Le, D. A. Duong, and T. V. Nguyen, "Yada: you always dream again for better object detection," *Multimedia Tools and Applications*, vol. 78, no. 19, pp. 28 189–28 208, 2019.

[13]  Z. Zou, K. Chen, Z. Shi, Y. Guo, and J. Ye, "Object detection in 20 years: A survey," *Proceedings of the IEEE*, 2023.

[14]  W. Liu, D. Anguelov, D. Erhan, C. Szegedy, S. Reed, C.-Y. Fu, and A. C. Berg, "Ssd: Single shot multibox detector," in *Computer Vision–ECCV 2016: 14th European Conference, Amsterdam, The Netherlands, October 11–14, 2016, Proceedings, Part I 14*. Springer, 2016, pp. 21–37.

[15]  X. Zhu, S. Lyu, X. Wang, and Q. Zhao, "Tph-yolov5: Improved yolov5 based on transformer prediction head for object detection on drone-captured scenarios," in *Proceedings of the IEEE/CVF international conference on computer vision*, 2021, pp. 2778–2788.

[16]  Y. Ma, L. Chai, L. Jin, Y. Yu, and J. Yan, "Avs-yolo: Object detection in aerial visual scene," *International Journal of Pattern Recognition and Artificial Intelligence*, vol. 36, no. 01, p. 2250004, 2022.

[17]  X. Fu, G. Wei, X. Yuan, Y. Liang, and Y. Bo, "Efficient yolov7-drone: An enhanced object detection approach for drone aerial imagery," *Drones*, vol. 7, no. 10, p. 616, 2023.

[18]  A. Vaswani, N. Shazeer, N. Parmar, J. Uszkoreit, L. Jones, A. N. Gomez, Ł. Kaiser, and I. Polosukhin, "Attention is all you need," *Advances in neural information processing systems*, vol. 30, 2017.

[19]  X. Zhu, W. Su, L. Lu, B. Li, X. Wang, and J. Dai, "Deformable detr: Deformable transformers for end-to-end object detection," *arXiv preprint arXiv:2010.04159*, 2020.

[20]  T. Ren, S. Liu, F. Li, H. Zhang, A. Zeng, J. Yang, X. Liao, D. Jia, H. Li, H. Cao *et al.*, "detrex: Benchmarking detection transformers," *arXiv preprint arXiv:2306.07265*, 2023.

# The Impact of Text Generation Techniques on Neural Image Captioning: An Empirical Study

Linna Ding[1], Mingyue Jiang[2]*, Liming Nie[3], Zuzhang Qing[4], Zuohua Ding[5]

Faculty of Computer Science and Technology, Zhejiang Sci-Tech University, Hangzhou, Zhejiang, China[1,2,5]

School of Computer Science and Technology, Nanyang Technological University, Singapore, Singapore[3]

Zhejiang Petroleum Integrated Energy Sales Co., Ltd, Hangzhou, Zhejiang, China[4]

*Abstract*—Image captioning is an advanced NLP task that has various practical applications. To meet the requirement of visual information understanding and textual information generation, the encoder-decoder framework has been widely adopted by image captioning models. In this context, the encoder is responsible for transforming an image into vector representation, and the decoder acts as a text generator for yielding an image caption. It is obvious and intuitive that the decoder is crucial for the entire image captioning model. However, there is a lack of comprehensive studies in which the impact of various aspects of the decoder on the image captioning is investigated. To advance the understanding of the impacts of text generation techniques employed by the decoder, we conduct an extensive empirical analysis of three types of language models, two types of decoding strategies and two types of training methods, based on four state-of-the-art image captioning models. Our experimental results demonstrate that the language model affects the performance of image captioning models, while different language models may benefit different image captioning models. In addition, it is also revealed that among the decoding and training strategies under investigation, the beam search, AOA mechanism and the reinforcement learning based training method can generally improve the performance of image captioning models. Moreover, the results also show that the combinational usage of these strategies always outperforms the use of single strategy for the task of image captioning.

*Keywords*—*Image captioning; encoder-decoder; text generation techniques*

## I. Introduction

Image captioning aims to provide accurate and textual descriptions for a given image. It is a challenging task integrating visual as well as textual understanding, and it involves technologies from both computer vision and natural language processing. Automatic image captioning has found practical applications in various domains, including social media [1], remote sensing [2], robotics [3], and medical image report generation [4].

Automatic image captioning has been receiving much attention in recent years, and a variety of approaches and strategies have been proposed and studied [5]. Although deep learning models have made significant progress in image captioning, describing images correctly remains a challenge. Image captioning models need to understand image content, object recognition, and object relationships while capturing the interaction between images and language to generate natural language descriptions.

Inspired by the advances in neural machine translation, most state-of-the-art image captioning models follow the encoder-decoder pipeline , which consists of an encoder and a decoder. Specifically, an encoder is used to transform an image into vector representations, and a decoder is used for translating the information from the encoder into natural sentences, yielding a relevant caption. In the literature, different encoders, decoders, and varying strategies supporting the encoding or decoding process have been investigated [5], [6].

As one of the core elements of image captioning, the decoder that acts as a text generator has attracted lots of research focuses. At first, various different language models have been employed as the decoder. Under the encoder-decoder framework, a mainstream image captioning model is CNN-RNN [7], where convolutional networks (CNN) are employed as the encoder for feature learning, followed by recurrent neural networks (RNN) act as a decoder for caption generation. Apart from that, various different models have been proposed and developed, including CNN-Long Short-Term Memory (LSTM) [8], CNN-Gated Recurrent Unit (GRU) [9], and CNN-Transformer [10]. On the other hand, different decoding strategies have been proposed and studied. Firstly, beam search has been widely adopted by RNN-based decoders for improving the quality of the output caption [11]. Secondly, to enhance the attention-based decoder, the attention on attention (AOA) strategy [12] has been proposed to extend the conventional attention mechanism. Last but not least, in order to enhance the decoder's capability of learning to predict the words appearing in the caption, various training strategies have been explored, including cross-entropy loss and reinforcement learning.

Naturally, different image captioning approaches employing varying strategies or mechanisms may have varying capabilities of generating captions. As can be seen from Fig. 1, for the same given input image, four different image captioning approaches provide four different captions, which are of varying quality as revealed by the evaluation metrics. In other words, different image captioning approaches may exhibit different captioning performance. However, due to the complexity of the image captioning models, the difference in performance may originate from the encoder, the decoder, or the relevant strategies. Recent studies have comprehensively analyzed the effect of different encoders on the model performance from an empirical perspective [13]–[18]. For the decoder part, its impacts on the image captioning performance have also been revealed and studied [19]–[22]. Nevertheless, there is still a lack of detailed and comprehensive investigations

---
*Corresponding authors.
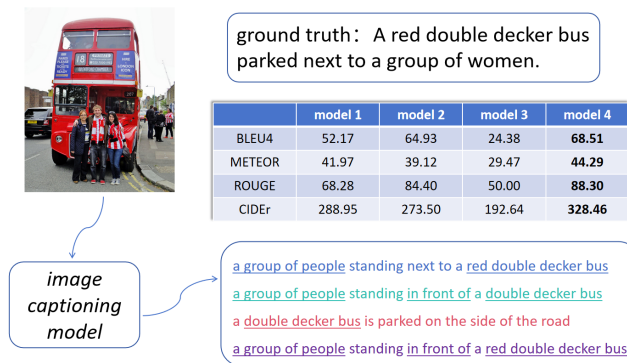
Fig. 1. For a given image, different image captioning approaches may yield varying captions.

of the impacts referring to various aspects of the decoder (including the language model, the decoding strategy, and training strategy).

To gain additional insights into the encoder-decoder based image captioning models, in this study, we conduct an extensive empirical study with the goal of comprehensively investigating the impacts of decoding related techniques on the performance of image captioning. We compared the impact of CNN-based, GRU-based, and LSTM-based decoders on image captioning models. In addition, we investigated the impacts of two types of decoding strategies, the search strategy (namely, the greedy search and the beam search) and the AOA mechanism.

We also analyzed the impacts of training methods on the performance of image captioning models and compared the impacts of two training methods, the Cross-Entropy Loss, and the reinforcement learning-based method. Furthermore, we investigated the impact of the combinational usage of these strategies.

We conducted experiments on the MSCOCO dataset [23], which is a widely-used dataset for the task of image captioning. We employed four state-of-the-art image captioning models as the basic models and further constructed a series of model variants from them by modifying the decoding parts of these basic models. To evaluate the performance of these image captioning models, we adopted six evaluation metrics, including BLUE1 [24], BLEU4 [24], METEOR [25], ROUGE [26], CIDEr [27] and SPICE [28]. Overall, our experimental results confirm the impacts of the language models, the decoding strategies, and the training strategies on the performance of image captioning models. More specifically, it is revealed that different language models may benefit different image captioning models, and the beam search, AOA mechanism, and the reinforcement learning based training method can generally improve the performance of image captioning models. In addition, it is also found that the combinational usage of various strategies can positively affect the captioning performance.

The contributions of this study are summarized as below.

- We conduct extensive experiments to empirically analyze the impacts of the decoder involving various text generation techniques on the performance of the image captioning models. Our study considers the impacts of

language models, decoding strategies, training strategies, and the combinational usage of decoding and training strategies, and accordingly evaluates the performance of 68 image captioning models (including 4 basic models and 64 model variants with varying usage of the language model, decoding strategy and training strategy).

- We highlight some practical findings. Our findings suggests that the performance of an image captioning model can be properly enhanced by configuring it with suitable language model as well as appropriate decoding and training strategies. This also provides a reference for further improving the performance of image captioning models.

The rest of the paper is structured as follows. Section II provides an in-depth discussion of previous research work We introduce some preliminary knowledge, including the commonly used language models, the decoding and training strategies for image captioning models, in Section III. In Section IV, we present our experimental design, including the research questions, the basic image captioning models employed in the experiments, the datasets and the evaluation metrics. Section V reports and discusses our experimental results to answer each of our research questions. Section VI concludes with a summary of this study and proposes directions for future research.

## II. RELATED WORK

***Image caption :*** Image captioning [29], [30], [31], [12] achieves significant improvements over the neural encoder-decoder framework [6]. The Show-Tell model [30] uses convolutional neural networks (CNNs) [32] to encode images into fixed-length vectors, and a Long short-term memory (LSTM) [33] as a decoder to sequentially generate words. To capture fine-grained visual details, attention-to-image captioning models [29], [31], [12] have been proposed to dynamically pin words together with relevant image parts during generation. To reduce exposure bias in sequence training, Rennie et al. [34] use reinforcement learning to optimize non-differentiable metrics. In order to further improve the accuracy, transformer models [10], [35] were proposed, allowing the model to effectively capture the relationship between different positions in the input sequence.
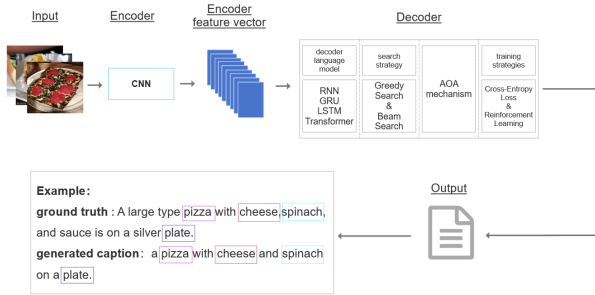
Fig. 2. Encoder-Decoder based image captioning.

***Empirical study :*** The factors that affect the image caption model are roughly divided into two parts: encoder and decoder. In order to study the impact of encoders on image caption models, people began to use different CNN encoders, such as Inception-V3, VGG, Resnet, Densenet, etc., for empirical research. Among them, [13], [14], [16] used ordinary LSTM as the decoder, [17] used MSprop as the optimizer on this basis, and [18] changed the decoder part from LSTM to GRU. In order to ensure the comprehensiveness of the experiment, [15], [36] also used LSTM and a combination of LSTM and visual attention mechanisms as decoders.

The research on the decoder part mainly focuses on the decoder architecture, search strategy and visual attention mechanism. Among them, [37] mainly focused on the impact of search strategies. [20] considered the influence of one-way and two-way LSTM decoders and search strategies. [19] selected the injection model and conducted experiments using different search strategies. [21] and [22] mainly focued on the impact of visual attention mechanism on the model. In addition, [22] takes into account the Transformer model.

While other papers have analyzed only one aspect of the attention mechanism, or two types of decoder architectures, we have built on this foundation by experimenting with RNNs, GRUs, LSTMs, and Transformers using different types of strategies as well as combinations of strategies, in order to have a more comprehensive analysis of decoder language models.

## III. PRELIMINARIES

This section briefly introduces the commonly used language models, as well as the strategies that are applicable to text generators, in the context of encoder-decoder based image captioning.

### A. Decoder Language Models

As shown in Fig. 2, the decoder of an image captioning model is responsible for translating the vector representation resulting from the encoder into a natural language caption. In the context of image captioning, the generation of captions can be formulated as a sequence to sequence learning task. Several language models have been employed to accomplish this task, including RNN, LSTM, GRU, and Transformer.

RNN [38] is used to process sequential data, but it does not handle long sequences and long-distance dependencies well due to vanishing or exploding gradient problems.

LSTM [33] is an improved RNN that effectively solves the gradient problem by introducing a gating mechanism, making it good at capturing long-term dependencies and achieving good results in tasks such as text generation and machine translation.

GRU [39] is an improved version of RNN. It uses a gating mechanism, has a simple structure and fewer parameters, and shows good performance in multiple sequence generation tasks, similar to LSTM.

Transformer [40] is a neural network based on a self-attention mechanism. It has global context modeling and parallel computing capabilities. It can comprehensively consider image features and subtitle sequences to generate accurate and coherent image subtitles.

### B. Decoding Strategies

Apart from the language model, the decoder can be equipped with various different strategies. In this study, we mainly focus on the search strategy and the strategies relating to the attention mechanism.

*1) Search Strategy:* Greedy search and beam search are two search strategies for generating sequences that are commonly used in the task of image captioning.

Greedy search is a sequence generation method that selects the currently optimal option each time without considering the global optimal solution. It is usually computationally efficient but may sacrifice final performance.

Beam search is a sequence generation method that considers multiple alternative outputs and selects the set of alternative outputs with the highest probability score to improve the quality of the generated results, often used in natural language processing and machine translation tasks.

*2) Attention on attention mechanism:* For encoder-decoder framework based image captioning, the attention mechanism is commonly applied for guiding the decoding process. The Attention on Attention (AOA) approach aims at extending the traditional attention mechanism applied to image captioning tasks.

The AOA approach consists of two main parts: the first part is the global attention module, which is used to compute global attention weights between image features and context vectors; the second part is the local attention module, which is used to compute local attention weights based on the global attention weights.

### C. Training Strategies

The training process aims to prepare the captioning model for learning to predict the probabilities of words that will appear in the caption. Two types of commonly adopted training strategies are Cross-Entropy Loss and reinforcement learning.

*1) Cross-entropy loss:* Traditional image captioning models are usually trained using maximum likelihood estimation (MLE) to optimize model parameters by minimizing cross-entropy loss. However, this method cannot directly measure subtitle quality and can easily lead to inaccurate or repeated subtitles.

*2) Reinforcement learning:* Training image captioning models using reinforcement learning has led to significant improvements. A typical method is self-criticism sequence training [34], which treats the generated subtitles as a sequence of actions, the quality is evaluated with the CIDEr-D metric, and the metric is maximized through reinforcement learning.

## IV. EXPERIMENTAL DESIGN

This section presents our research questions, basic image captioning models, datasets, and evaluation metrics.

### A. Research Questions

We plan to investigate the following four research questions.

- **RQ1:** What is the impact of the language models on the performance of image captioning models?

- **RQ2:** How do different decoding strategies affect the performance of image captioning?
  RQ2.1: How does beam search compare to greedy search for the task of image captioning?
  RQ2.2: What is the impact of using the AOA mechanism with the language model on the performance of image captioning?

- **RQ3:** How do different training strategies used for the decoder impact the performance of image captioning?

- **RQ4:** What is the impact of the combinational usage of various strategies of the decoder on the performance of image captioning?

### B. Basic Image Captioning Models

In this study, we employed four state-of-the-art image captioning models as the basic models, based on which we constructed various model variants (the details are elaborated in Section V). The information of these models is summarized in Table I, and further described below.

**FC** [34]: The FC model utilizes a deep CNN model ResNet101 to encode the input picture, and then a linear map is used for embedding. The model uses an LSTM-based decoder.

**Att2in2** [34] : The Att2in2 model uses ResNet101 as an encoder and LSTM as a decoder. Particularly, it is an image captioning model involving the attention mechanism. The model is an improved version of the subtitle attention model [31].

**Up-Down** [29] : The up-Down model encoder part uses Faster R-CNN ResNet101, which is a classical target detection model, and local features from an image, and the decoder part employs a two-layer LSTM architecture (Top-Down Attention LSTM and Language LSTM), which utilizes both bottom-up and top-down attentional mechanisms, in order to generate natural language descriptions that match the content of the image.

**Transformer** [40] : The Transformer model uses Faster R-CNN ResNet101 as the encoder and employs a Transformer as the decoder. The Transformer decoder is an integral part of the Transformer model and is used to convert the input

sequence generated by the encoder into a target sequence. It gradually generates target sequences through the self-attention mechanism and encoder-decoder attention mechanism.

As shown in Table I , the encoders of the above four models are either Faster R-CNN Resnet101 [41] or ResNet101 [32]. We further detail these two models as below.

**ResNet101** [32]: ResNet101 is a CNN model having 101 layers. It is a variant of a Residual Network, and it introduces residual connections to solve the problem of gradient disappearance and gradient explosion in deep network training. Compared with traditional shallow networks, it can learn image features at a deeper level, thereby extracting more complex and advanced feature expressions.

**Faster R-CNN ResNet101** [41]: Faster R-CNN ResNet101 combines the Faster R-CNN object detection algorithm and the ResNet101 feature extractor. As a feature extractor, ResNet101 can efficiently extract features from images. Faster R-CNN ResNet101 combines the efficiency of the target detection algorithm and the deep feature learning ability of ResNet101, making the model perform well in target detection tasks.

### C. Dataset

Our experiments are conducted on the MSCOCO dataset [23], which is a popular benchmark for image captioning tasks, containing 123,287 images, each with 5 captions, for a total of 615,935 captions. We use the "Karpathy" data split [42], with 5,000 images for validation, 5,000 for testing, and the rest for training.

To preprocess the captions, we generated a vocabulary of 10,369 unique words by converting sentences to lowercase and removing words that appeared less than five times.

## V. EXPERIMENTAL RESULTS

This section analyzes and reports our experimental results. Specifically, for each RQ, we discuss the motivation, present the approach, and finally report the results.

### A. RQ1: Impact of Language Models on the Task of Image Captioning

**Motivation:** For an encoder-decoder based image captioning model, the language model constitutes the key part of the decoder, and thus it is crucial to the overall performance of image captioning. Prior studies have proposed various language models for supporting the decoding stage of image captioning [5]. Yet, there is still a lack of empirical evidence revealing the extent of the impact, and it is also unclear how different language models affect the performance of image captioning models. Therefore, in this RQ, we investigated image captioning models with varying language models, in order to reveal the impact of language models on the performance of image captioning models.

**Approach:** First, we utilized the three baseline models employing an RNN-based language model (namely, FC, Att2in2, and Up-Down) by following their original configurations in the prior studies [12]. Secondly, we constructed six model variants from the three baseline models by modifying the decoder part. That is, for each model, two variants were constructed by

TABLE I. BASIC INFORMATION OF THE SELECTED MODEL

| Model | Encoder | Decoder | Search Strategy | Attention |
|---|---|---|---|---|
| FC | ResNet101 | LSTM | Greedy | |
| Att2in2 | ResNet101 | LSTM | Greedy | ✓ |
| Up-Down | Faster R-CNN ResNet101 | Attention LSTM +Language LSTM | Greedy | ✓ |
| Transformer | Faster R-CNN ResNet101 | Self-Attention mechanism+feed-forward neural network | Greedy | ✓ |

replacing its default language model LSTM with an RNN and a GRU, respectively. For the sake of simplicity, we utilized $M \diamondsuit L$ to denote a model $M$ supported with the specific language model $L$. For example, FC$\diamondsuit$RNN represents one variant of model FC where the default language model LSTM is replaced with an RNN. Thirdly, for each of the models obtained in the previous steps, we further constructed a variant for each of them by modifying its encoder model (i.e. from ResNet101 to Fast RCNN ResNet101, or vice versa). Finally, we evaluated these 18 models (including three baseline models and 15 model variants) and collected evaluation results on a series of evaluation metrics.

*Results:* Tables II and III, respectively report the evaluation results of nine models employing the same encoder model. Based on these results, we make the following observations.

1) *The use of different language models leads to varying performance of the image captioning model.* As shown in Table II, for each of the models, the use of RNN, GRU, or LSTM as the decoder model yields different values for each of the six evaluation metrics. For example, the BLEU1 values for the three models, that is, FC$\diamondsuit$RNN, FC$\diamondsuit$GRU, and the original FC model are 73.70, 73.71, and 74.06, respectively. Table III consistently reveals this point.

2) *The language model affects different image captioning models in different ways.* At first, it is observed that the language model may have opposite impacts on different image captioning models. Consider the FC and Att2in2 models as an example. According to Table II, compared to the use of RNN, the use of GRU positively contributes to the BLEU1 value of FC (the BLEU1 values of FC$\diamondsuit$RNN and FC$\diamondsuit$GRU are 73.70 and 73.71), while it negatively affects the BLEU1 value of Att2in2 (the BLEU1 values of Att2in2$\diamondsuit$RNN and Att2in2$\diamondsuit$GRU are 75.56 and 75.11). On the other hand, the degrees of the impacts of the language models may also be different when they are applied to different image captioning models. As can be observed from Table III, FC$\diamondsuit$GRU outperforms FC$\diamondsuit$RNN in terms of the CIDEr metric, exhibiting a discrepancy of 1.65 (97.72 vs. 96.07). Nevertheless, although Att2in2$\diamondsuit$GRU also outperforms Att2in2$\diamondsuit$RNN in terms of the CIDEr metric, the discrepancy in the performance is relatively tiny (0.14).

3) *The best language model for different image captioning models may be different.* Among the three language models under investigation (that is, RNN, GRU, and LSTM), they are beneficial to different image captioning models. For the models employing the faster R-CNN ResNet101 as the encoder, the best language model for the FC model is LSTM; while the Up-Down model exhibits the best performance with the GRU as the language model (as observed from Table II). Quite differently, for the models employing ResNet101 as the encoder, the FC model performs best with GRU, the Att2in2

model achieves the best performance with LSTM, while the Up-Down model performs best with RNN (as observed from Table III).

> **RQ1** : For the encoder-decoder based image captioning models, employing different language models as the decoder always leads to varying captioning performance. Nevertheless, the impact of the language models on different image captioning models may vary, and accordingly, the good language models may also be different from the perspective of different image captioning models.

### B. RQ2: Impact of Different Decoding Strategies on Image Captioning Models

*Motivation:* At present, the endoer-decoder based image captioning models have been extended and enhanced via a variety of decoding strategies [5]. Although these decoding strategies have been demonstrated to be able to positively contribute to captioning performance, they have not been comprehensively investigated on the same set of image captioning models and datasets. To fill this gap, in this RQ, we empirically studied the impacts of two types of decoding strategies, the search strategy and the AOA mechanism.

*Approach:* We first focus on the search strategies adopted by the decoder of the image captioning model. To this end, we conducted experiments on 20 models, including the 18 models constructed for RQ1, the basic Transformer model and its variant employing the RestNet101 instead of the Faster R-CNN ResNet101 as the encoder. It is noted that all of these 20 models adopt the greedy search (as reported in Table I). Based on these, we further constructed 20 model variants from them by replacing the greedy search with beam search. In particular, the latter set of models is configured with various beam sizes (in this study, we adopted four beam sizes, 2, 3, 4, and 5). As a result, there are 20 groups of models, each of which consists of two models sharing the same technical details except for the search strategy. We evaluated all of these models on the dataset and compared the performances of models within individual groups.

To study the impacts of the AOA mechanisms, the three base models, Att2in2, Up-Down, and Transformer, and their variants are utilized. The FC model and its variants are excluded because they do not employ the attention mechanism and thus the AOA mechanism is not applicable. For each of the models, we constructed a variant for it by additionally applying the AOA mechanism, and then conducted a comparison analysis of their performance.

*Results:* Fig. 3 reports the performance comparison results of image captioning models using or not using the beam search strategy. Particularly, Fig. 3 (a)-(f) reports the results for the ten

TABLE II. Evaluation Results of the Nine Models Employing Faster R-CNN ResNet101 as the Encoder. Among Each Basic Model and its Variants, the Best Performance in Terms of Individual Metrics is Highlighted with Bold Type. Furthermore, the Best Performer in Terms of Individual Metrics is Underlined

| Model | Decoder Language Model | BLEU1 | BLEU4 | METEOR | ROUGE | CIDEr | SPICE |
|---|---|---|---|---|---|---|---|
| FC | RNN | 73.70 | 30.86 | 25.82 | 53.93 | 100.83 | 19.10 |
| | GRU | 73.71 | 31.19 | 25.97 | 54.19 | 102.04 | **19.26** |
| | LSTM | **74.06** | **31.42** | **26.07** | **54.38** | **102.53** | 19.21 |
| Att2in2 | RNN | 75.56 | **33.51** | 26.70 | 55.41 | **108.95** | **20.12** |
| | GRU | 75.11 | 32.98 | **26.74** | 55.40 | 107.57 | 20.05 |
| | LSTM | **75.97** | 33.49 | 26.67 | **55.46** | 108.14 | 20.10 |
| Up-Down | RNN | 75.60 | 33.81 | 27.16 | 55.72 | 110.60 | 20.34 |
| | GRU | **76.17** | **34.34** | **27.37** | **56.18** | **112.21** | 20.54 |
| | LSTM | 75.64 | 33.88 | 27.34 | 55.94 | 111.90 | **20.60** |

TABLE III. Evaluation Results of the Nine Models Employing ResNet101 as the Encoder

| Model | Decoder Language Model | BLEU1 | BLEU4 | METEOR | ROUGE | CIDEr | SPICE |
|---|---|---|---|---|---|---|---|
| FC | RNN | 71.89 | 29.24 | 25.08 | 52.80 | 96.07 | 18.25 |
| | GRU | **72.37** | **29.76** | **25.38** | **53.08** | **97.72** | **18.46** |
| | LSTM | 72.29 | 29.51 | 25.25 | 53.01 | 96.68 | 18.30 |
| Att2in2 | RNN | 74.77 | 32.47 | **26.53** | 54.87 | 105.44 | 19.74 |
| | GRU | **74.83** | 32.41 | 26.33 | 54.74 | 105.58 | 19.71 |
| | LSTM | 74.75 | **32.89** | 26.47 | **54.95** | **106.67** | **19.96** |
| Up-Down | RNN | **74.81** | 32.27 | **26.72** | **55.03** | **107.31** | **20.03** |
| | GRU | 74.54 | **32.42** | 26.71 | 54.87 | 106.73 | 19.80 |
| | LSTM | 74.46 | 31.98 | 26.60 | 54.81 | 106.43 | 19.84 |

groups of models employing the faster R-CNN ResNet101 as the encoder, where each subfigure focuses on the comparison of performance with respect to one of the evaluation metrics. Accordingly, the comparison results relating to the other ten groups of models that using the ResNet101 as the encoder are reported in 3 (g)-(l). Fig. 4 further reports the performance comparison results on seven groups of models applying or not applying the AOA mechanism. Based on these results, we have the following observations:

1) ***The use of different decoding strategies affects the performance of image captioning models.*** It can be observed from Fig. 3 that using greedy search or beam search leads to varying captioning performance of the relevant models. Similarly, Fig. 4 also shows that every image captioning model under investigation exhibits different performance with and without using the AoA mechanism.

2) ***Compared to greedy search, the use of beam search generally improves the captioning performance.*** Firstly, it can be observed from Fig. 3 that most of the models achieve better performance by using beam search. This indicates that the use of beam search is beneficial to image captioning models. On the other hand, it can also be found that the optimal beam size of the beam search for different models varies. Nevertheless, for the majority of models, the best performance is reached with a beam size of 2.

3) ***The application of the AoA mechanism benefits most of the image captioning models under investigation.*** Fig. 4 shows that after additional applying the AoA mechanism on the target image captioning models, the captioning performance has been improved in most cases (that is, for most of the models with respect to the majority of evaluation metrics). Although there are some models for which the application of the AoA mechanism leads to a decrease in captioning performance (i.e., the Up-Down model employing the encoder of faster R-CNN ResNet101), the extent of the decrease is relatively smaller than the extent of the increases resulted from

using the AoA mechanism.

> **RQ2** : For encoder-decoder based image captioning models, the application of decoding strategies affects the captioning performance.Specifically, the use of beam search always outperforms the use of greedy search, and most models exhibit the best performance with the beam search configured with a beam size of 2. Moreover, the application of the AoA mechanism is beneficial to most of the image captioning models under investigation.

*C. RQ3: Impact of the Training Strategies on Image Captioning Models*

***Motivation:*** Currently, encoder-decoder based image captioning models have emerged with various training methods. However, no prior study has focused on revealing the effect of training methods applied on the decoder part. Hence, in this RQ, we empirically studied two training approaches (Cross-Entropy Loss and Reinforcement Learning) and their impacts on captioning performance.

***Approach:*** In the experiments, we reused the 20 image captioning models, including the FC, Att2in2, and Up-Down models employing the RNN, GRU, and LSTM in the decoder part as well as the Transformer model, and also their relevant variants using a different CNN (faster R-CNN ResNet101 or ResNet101) as the encoder. Noted that all of these models are trained by following their default method, namely, the cross-entropy loss method. Based on each of these models, we further constructed a model variant by training its decoder via a reinforcement learning based method, the self-critical sequence training method. These result in 20 groups of model, where each group consists of a model and its variant involving a decoder trained via reinforcement learning. We evaluated these newly constructed model variants and further conducted a comparison analysis with individual groups.
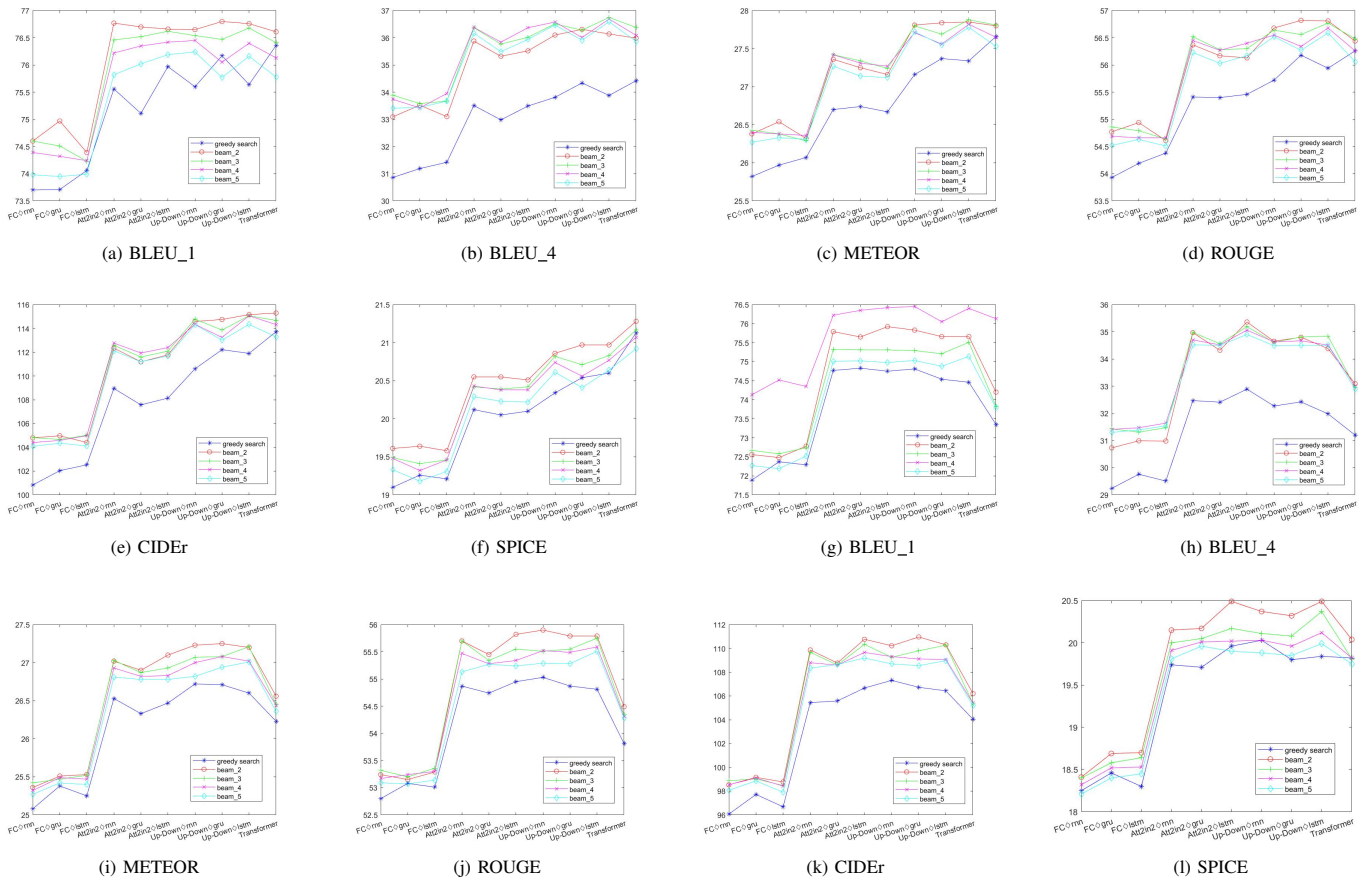
Fig. 3. Comparison of models employing the greedy search with those employing the beam search. For the latter, various beam sizes (2, 3, 4 and 5) have been investigated. A total number of 20 groups of models are studied, including ten groups of models using Faster R-CNN ResNet101 ((a) - (f)) and another ten groups of models using ResNet101 ((g) - (l)).

**Results:** Tables IV and V, respectively report the evaluation results of ten newly constructed models employing the same encoder model. For each newly constructed model (where the decoder is trained via reinforcement learning), we further compared its performance with the relevant model that trained via the cross-entropy loss method (as reported in Tables II and III). Accordingly, Tables IV and V further report the improvements made by applying the reinforcement learning based training method (the improvement is indicated by the ↑). Based on these results, we make the following observations:

1) ***Reinforcement learning is an effective training method for supporting the task of image captioning.*** Both Table IV and Table V reveal that training the decoder by the self-critical sequence training method leads performance improvement for all of the target models. For example, after applying the self-critical sequence training method, FC◇RNN exhibits 4.02 improvement in terms of the BLEU1 metric, while the improvement is 12.24 with respect to the CIDEr metic (as shown in the first row of Table IV).

2) ***The performance improvements made by reinforcement learning are different for different image captioning models.*** According to Table IV, the performance improvements obtained via self-critical sequence training range from 0.59 to 14.16. Similarly, as shown in Table V, the highest increase

in performance is 12.92, and the lowest increase is 0.46. Furthermore, it can be observed that the application of the reinforcement learning based training method leads to varying performance improvement for every of the target models.

---

**RQ3** : For encoder-decoder based image captioning models, training the decoder with reinforcement learning will improve the model performance. Nevertheless, the degree of the improvements is different for different image captioning models.

---

*D. Impact of the Combinational Usage of Decoding Strategies on the Performance of Image Captioning Models*

**Motivation:** We have previously investigated the effect of every single strategy or mechanism on the performance of image captioning models. With the observation that these strategies and mechanisms can be applied to an image captioning model together, in this RQ, we further studied the effect of the application of various combinations of these strategies.

**Approach:** We utilized the four baseline models employing the faster R-CNN ResNet101 encoder as the basic model. We further considered the combination of the three strategies or methods, that is, the search strategy, the AoA mechanism, and the training method. We use $P_{xyz}$ to denote the application
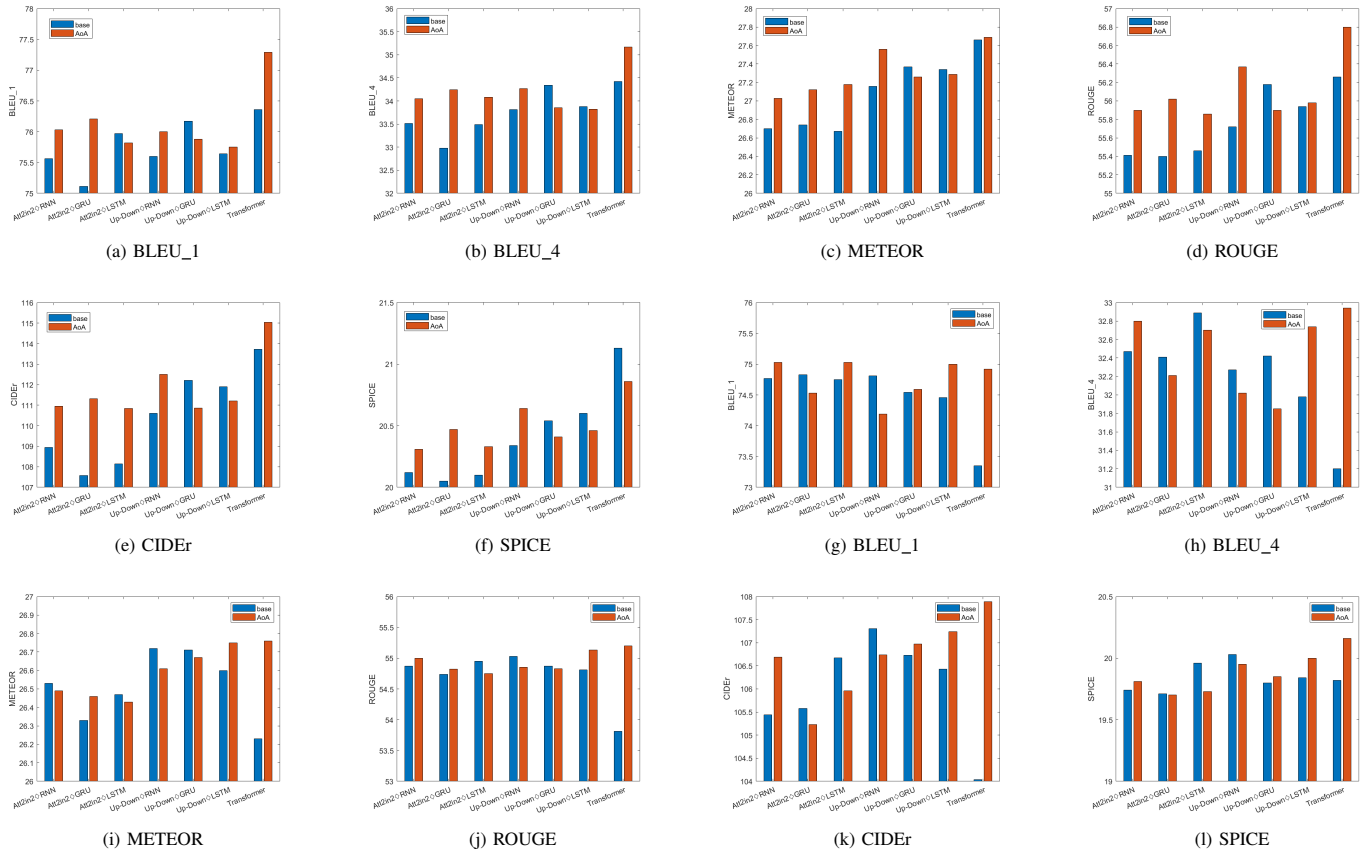
Fig. 4. Comparison of the 14 groups of models, including seven groups of models using Faster R-CNN ResNet101 ((a) - (f)) and another seven groups of models using ResNet101 ((g) - (l)). In each group, one model does not using AoA (denoted as *base*), while the other one applies AoA (denoted by AoA).

TABLE IV. Performance of Models with the Faster R-CNN ResNet101 as Encoder and with the Decoder Trained with Self-critical Sequence Training Method. ↑ Denotes the Rate of Improvements Achieved by Applying the Reinforcement Learning Training Method. For each Evaluation Metric, the Largest Improvement is Highlighted by Underling

| Model | Decoder Language Model | BLEU1 | BLEU4 | METEOR | ROUGE | CIDEr | SPICE |
|---|---|---|---|---|---|---|---|
| FC | RNN | 77.72 ↑ 4.02 | 34.83 ↑ 3.97 | 26.89 ↑ 1.07 | 56.33 ↑ 2.41 | 113.07 ↑ 12.24 | 20.20 ↑ 1.10 |
| | GRU | 77.74 ↑ 4.03 | 34.62 ↑ 3.43 | 26.79 ↑ 0.81 | 56.16 ↑ 1.97 | 114.08 ↑ 12.05 | 20.05 ↑ 0.79 |
| | LSTM | 77.37 ↑ 3.31 | 34.69 ↑ 3.26 | 26.65 ↑ 0.59 | 56.17 ↑ 1.79 | 113.04 ↑ 10.51 | 19.99 ↑ 0.78 |
| Att2in2 | RNN | 78.53 ↑ 2.97 | 36.46 ↑ 2.96 | 27.39 ↑ 0.68 | 57.17 ↑ 1.77 | 119.48 ↑ 10.53 | 20.84 ↑ 0.73 |
| | GRU | 78.58 ↑ 3.48 | 36.27 ↑ 3.29 | 27.45 ↑ 0.71 | 57.16 ↑ 1.75 | 119.25 ↑ 11.68 | 21.01 ↑ 0.97 |
| | LSTM | 78.46 ↑ 2.48 | 36.07 ↑ 2.59 | 27.38 ↑ 0.71 | 57.14 ↑ 1.67 | 119.13 ↑ 10.99 | 20.87 ↑ 0.77 |
| Up-Down | RNN | 79.88 ↑ 4.28 | 37.73 ↑ 3.92 | 28.20 ↑ 1.04 | 58.15 ↑ 2.42 | 124.76 ↑ 14.16 | 21.45 ↑ 1.11 |
| | GRU | 79.65 ↑ 3.48 | 37.26 ↑ 2.92 | 28.18 ↑ 0.80 | 57.89 ↑ 1.71 | 124.02 ↑ 11.81 | 21.55 ↑ 1.00 |
| | LSTM | 79.62 ↑ 3.97 | 37.24 ↑ 3.36 | 28.11 ↑ 0.77 | 57.83 ↑ 1.89 | 124.57 ↑ 12.67 | 21.52 ↑ 0.92 |
| Transformer | Transformer | 79.46 ↑ 3.09 | 38.04 ↑ 3.63 | 28.54 ↑ 0.88 | 57.94 ↑ 1.69 | 123.97 ↑ 10.26 | 22.20 ↑ 1.07 |

TABLE V. Performance of Models with the ResNet101 as Encoder and Trained with Self-critical Sequence Training Method

| Model | Decoder Language Model | BLEU1 | BLEU4 | METEOR | ROUGE | CIDEr | SPICE |
|---|---|---|---|---|---|---|---|
| FC | RNN | 75.89 ↑ 4.00 | 33.10 ↑ 3.86 | 25.95 ↑ 0.87 | 55.10 ↑ 2.03 | 107.78 ↑ 11.71 | 19.32 ↑ 1.08 |
| | GRU | 76.16 ↑ 3.79 | 33.15 ↑ 3.39 | 26.14 ↑ 0.76 | 55.11 ↑ 2.03 | 108.98 ↑ 11.26 | 19.47 ↑ 1.01 |
| | LSTM | 76.33 ↑ 4.05 | 33.46 ↑ 3.94 | 26.19 ↑ 0.94 | 55.27 ↑ 2.25 | 107.91 ↑ 11.23 | 19.40 ↑ 1.10 |
| Att2in2 | RNN | 77.71 ↑ 2.94 | 35.51 ↑ 3.04 | 26.99 ↑ 0.46 | 56.64 ↑ 1.77 | 116.59 ↑ 11.15 | 20.44 ↑ 0.71 |
| | GRU | 77.70 ↑ 2.86 | 35.34 ↑ 2.93 | 27.04 ↑ 0.71 | 56.56 ↑ 1.82 | 116.79 ↑ 11.21 | 20.50 ↑ 0.79 |
| | LSTM | 77.85 ↑ 3.10 | 35.35 ↑ 2.46 | 26.96 ↑ 0.49 | 56.63 ↑ 1.68 | 116.09 ↑ 9.42 | 20.44 ↑ 0.48 |
| Up-Down | RNN | 78.57 ↑ 3.76 | 36.03 ↑ 3.76 | 27.54 ↑ 0.82 | 57.11 ↑ 2.07 | 119.56 ↑ 12.24 | 20.98 ↑ 0.96 |
| | GRU | 78.81 ↑ 4.27 | 35.79 ↑ 3.36 | 27.58 ↑ 0.86 | 57.06 ↑ 2.19 | 119.42 ↑ 12.69 | 21.00 ↑ 1.20 |
| | LSTM | 78.76 ↑ 4.30 | 35.82 ↑ 3.84 | 27.56 ↑ 0.95 | 56.99 ↑ 2.18 | 119.35 ↑ 12.92 | 21.14 ↑ 1.30 |
| Transformer | Transformer | 76.77 ↑ 3.42 | 34.90 ↑ 3.69 | 27.25 ↑ 1.02 | 55.78 ↑ 1.96 | 115.37 ↑ 11.33 | 21.31 ↑ 1.48 |

of one combination of these three strategies, where $x = 1$, $y = 1$, and $z = 1$ respectively represent the use of the beam search, AoA mechanism, and the self-critical sequence training methods. For example, $P_{110}$ denotes that the beam search and

AoA mechanism are applied together, while $P_{011}$ represents that the AoA mechanism and the self-critical sequence training method are applied together.

We further applied various combinations of different strategies on every basic model to construct some model variants. For the FC model, since it does not support the attention mechanism, only $P_{101}$ (that is, beam search and the self-critical sequence training) is applicable. Accordingly, one model variant was constructed from the FC model. For the other three basic models, four different combinations of these strategies are applicable (namely, $P_{101}$, $P_{110}$, $P_{011}$, and $P_{111}$), and thus four model variants were constructed from each of them. At last, these model variants were evaluated on the dataset.

*Results:* Table VI reports the evaluation results of 13 model variants employing some combination of the strategies or methods applied on the decoder part. Noted that for each model variant, its relevant models employing one of these strategies have already been evaluated and investigated in the previous RQs, we thus compare it with the one exhibiting the best performance in order to report the performance improvement achieved via the application of combined strategies (the performance improvement is shown in Table VI). Based on these results, we make the following observations:

*1) The combination of various strategies helps to improve the performance of image captioning models in most cases.* Table VI shows that the captioning performance is improved in most cases (i.e., most of the evaluated metrics for most models) after using the combination strategy on the target image captioning models. Although the application of the combination strategy to some models leads to a decrease in their captioning performance (e.g., the Att2in2 model with the usage of the beam search and self-critical sequence training method), the decrease is relatively small.

*2) Different combinations of methods have different effects on the performance enhancement.* As can be seen from the Table VI, the model performance improvement is different for different models using the same combination of strategies, and the model performance improvement is also different for the same model using different combinations of strategies. Nevertheless, it is observed that for the three models to which variuos combinations of strategies have been applied, they exhibit the best performance with $P_{111}$. That is, by applying the beam search, the AoA mechanism, and the reinforcement learning based training method together, these models perform better than those equipped with only parts of these strategies.

---

**RQ4** : For encoder-decoder based image captioning models, applying various strategies to the decoder is helpful for improving the overall captioning performance. For the image captioning models under investigation, they exhibit the best performance with the use of the beam search, AoA mechanism and the reinforcement learning based training method.

---

## VI. Conclusion

In this work, we focus on the impact of various aspects of the decoder on image captioning. In order to understand the impact of the text generation technique employed by the decoder on the results, we have conducted an extensive empirical analysis involving three different language models, two different decoding strategies, and two different training methods. The results of the research and analysis show that different language models have different impacts on the performance of the generated subtitles. Meanwhile, the use of two different decoding strategies as well as the training method of reinforcement learning helps to improve the model performance. In addition, it was found that using a combination of these strategies is usually better than using only a single strategy in image subtitle generation tasks. Future research directions can consider expanding our research to more complex datasets, especially exploring in cross-cultural environments. In addition, further research on how to integrate other machine learning technologies, such as transfer learning, to further improve model performance is also an important direction. The development of these future works will help expand our research and have a broader impact.

## References

[1] Y.-T. Chen, F. Chen, M. Cooper, and D. Joshi, "Using business-aware latent topics for image captioning in social media," in *2016 IEEE International Conference on Multimedia and Expo (ICME)*, 2016, pp. 1–6.

[2] Q. Wang, W. Huang, X. Zhang, and X. Li, "Word–sentence framework for remote sensing image captioning," *IEEE Transactions on Geoscience and Remote Sensing*, vol. 59, no. 12, pp. 10 532–10 543, 2020.

[3] R. C. Luo, Y.-T. Hsu, Y.-C. Wen, and H.-J. Ye, "Visual image caption generation for service robotics and industrial applications," in *2019 IEEE International Conference on Industrial Cyber Physical Systems (ICPS)*, 2019, pp. 827–832.

[4] C. Yin, B. Qian, J. Wei, X. Li, X. Zhang, Y. Li, and Q. Zheng, "Automatic generation of medical imaging diagnostic report with hierarchical recurrent neural network," in *2019 IEEE international conference on data mining (ICDM)*, 2019, pp. 728–737.

[5] M. Stefanini, M. Cornia, L. Baraldi, S. Cascianelli, G. Fiameni, and R. Cucchiara, "From show to tell: A survey on deep learning-based image captioning," *IEEE transactions on pattern analysis and machine intelligence*, vol. 45, no. 1, pp. 539–559, 2022.

[6] M. Z. Hossain, F. Sohel, M. F. Shiratuddin, and H. Laga, "A comprehensive survey of deep learning for image captioning," *ACM Computing Surveys (CsUR)*, vol. 51, no. 6, pp. 1–36, 2019.

[7] Q. You, H. Jin, Z. Wang, C. Fang, and J. Luo, "Image captioning with semantic attention," in *Proceedings of the IEEE conference on computer vision and pattern recognition*, 2016, pp. 4651–4659.

[8] C. Wang, H. Yang, C. Bartz, and C. Meinel, "Image captioning with deep bidirectional lstms," in *Proceedings of the 24th ACM international conference on Multimedia*, 2016, pp. 988–997.

[9] J.-B. Delbrouck and S. Dupont, "Bringing back simplicity and lightliness into neural image captioning," *arXiv preprint arXiv:1810.06245*, 2018.

[10] S. Herdade, A. Kappeler, K. Boakye, and J. Soares, "Image captioning: Transforming objects into words," *Advances in neural information processing systems*, vol. 32, 2019.

TABLE VI. EVALUATION RESULTS OF MODELS APPLYING MULTIPLE (COMBINED) STRATEGIES. BY COMPARING EACH MODEL (THAT APPLY AT LEAST TWO TYPES OF STRATEGIES TOGETHER) WITH THE BEST ONE APPLYING ONLY ONE OF SUCH STRATEGIES, THE IMPROVEMENT ACHIEVED VIA COMBINATIONAL USAGE OF VARIOUS STRATEGIES IS REPORTED (↑ AND ↓ REPRESENT THE POSITIVE AND NEGATIVE IMPROVEMENTS, RESPECTIVELY

|  | FC | Att2in2 | | | | Up-Down | | | | Transformer | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  | $P_{(101)}$ | $P_{(101)}$ | $P_{(110)}$ | $P_{(011)}$ | $P_{(111)}$ | $P_{(101)}$ | $P_{(110)}$ | $P_{(011)}$ | $P_{(111)}$ | $P_{(101)}$ | $P_{(110)}$ | $P_{(011)}$ | $P_{(111)}$ |
| BLEU1 | 77.40 ↑0.03 | 78.46 ↑0.00 | 76.52 ↑0.70 | 78.49 ↑0.03 | 78.57 ↑0.12 | 79.86 ↑0.24 | 76.54 ↑0.79 | 79.80 ↑0.18 | 80.09 ↑0.48 | 80.15 ↑0.70 | 76.85 ↓0.44 | 80.47 ↑1.01 | 80.75 ↑1.29 |
| BLEU4 | 34.83 ↑0.14 | 36.09 ↑0.01 | 36.36 ↑2.28 | 36.30 ↑0.23 | 36.43 ↑0.36 | 37.60 ↑0.36 | 35.86 ↑2.04 | 37.54 ↑0.30 | 37.93 ↑0.69 | 38.76 ↑0.72 | 37.18 ↑2.01 | 38.97 ↑0.93 | 39.19 ↑1.15 |
| METEOR | 26.71 ↑0.06 | 27.29 ↓0.09 | 27.55 ↑0.36 | 27.44 ↑0.06 | 27.47 ↑0.09 | 28.16 ↑0.05 | 27.71 ↑0.42 | 28.30 ↑0.19 | 28.36 ↑0.25 | 28.79 ↑0.25 | 28.03 ↑0.34 | 28.97 ↑0.43 | 29.00 ↑0.46 |
| ROUGE | 56.27 ↑0.11 | 57.10 ↓0.04 | 56.54 ↑0.69 | 57.23 ↑0.09 | 57.27 ↑0.14 | 57.94 ↑0.11 | 56.59 ↑0.61 | 58.09 ↑0.26 | 58.22 ↑0.40 | 58.36 ↑0.42 | 57.16 ↑0.36 | 58.79 ↑0.85 | 58.88 ↑0.94 |
| CIDEr | 113.50 ↑0.46 | 118.75 ↓0.38 | 113.17 ↑2.32 | 119.76 ↑0.63 | 119.94 ↑0.81 | 124.88 ↑0.31 | 113.86 ↑2.66 | 124.91 ↑0.34 | 125.52 ↑0.95 | 127.33 ↑3.35 | 116.58 ↑1.53 | 127.41 ↑3.44 | 128.85 ↑4.87 |
| SPICE | 20.05 ↑0.06 | 20.78 ↓0.09 | 20.41 ↑0.08 | 20.86 ↓0.01 | 20.86 ↓0.01 | 21.56 ↑0.04 | 20.80 ↑0.34 | 21.81 ↑0.29 | 21.88 ↑0.36 | 22.55 ↑0.35 | 21.08 ↑0.21 | 22.45 ↑0.24 | 22.58 ↑0.37 |

[11] M. Freitag and Y. Al-Onaizan, "Beam search strategies for neural machine translation," *arXiv preprint arXiv:1702.01806*, 2017.

[12] L. Huang, W. Wang, J. Chen, and X.-Y. Wei, "Attention on attention for image captioning," in *Proceedings of the IEEE/CVF international conference on computer vision*, 2019, pp. 4634–4643.

[13] A. Pal, S. Kar, A. Taneja, and V. K. Jadoun, "Image captioning and comparison of different encoders," in *Journal of Physics: Conference Series*, vol. 1478. IOP Publishing, 2020, p. 012004.

[14] V. Atliha and D. Šešok, "Comparison of vgg and resnet used as encoders for image captioning," in *2020 IEEE Open Conference of Electrical, Electronic and Information Sciences (eStream)*, 2020, pp. 1–4.

[15] S. Katiyar and S. K. Borgohain, "Comparative evaluation of cnn architectures for image caption generation," *arXiv preprint arXiv:2102.11506*, 2021.

[16] V. Sri Neha, B. Nikhila, K. Deepika, and T. Subetha, "A comparative analysis on image caption generator using deep learning architecture—resnet and vgg16," in *Computational Vision and Bio-Inspired Computing: Proceedings of ICCVBIC 2021*. Springer, 2022, pp. 209–218.

[17] M. S. Alam, M. S. Rahman, M. I. Hosen, K. A. Mubin, S. Hossen, and M. Mridha, "Comparison of different cnn model used as encoders for image captioning," in *2021 International Conference on Data Analytics for Business and Industry (ICDABI)*, 2021, pp. 523–526.

[18] Gaurav and P. Mathur, "Empirical study of image captioning models using various deep learning encoders," in *International Conference on Machine Intelligence and Signal Processing*. Springer, 2022, pp. 305–316.

[19] K. R. Suresh, A. Jarapala, and P. Sudeep, "Image captioning encoder–decoder models using cnn-rnn architectures: A comparative study," *Circuits, Systems, and Signal Processing*, vol. 41, no. 10, pp. 5719–5742, 2022.

[20] S. Takkar, A. Jain, and P. Adlakha, "Comparative study of different image captioning models," in *2021 5th International Conference on Computing Methodologies and Communication (ICCMC)*, 2021, pp. 1366–1371.

[21] P. P. Khaing *et al.*, "Attention-based deep learning model for image captioning: a comparative study," *International Journal of Image, Graphics and Signal Processing*, vol. 11, no. 6, p. 1, 2019.

[22] P. Dandwate, C. Shahane, V. Jagtap, and S. C. Karande, "Comparative study of transformer and lstm network with attention mechanism on image captioning," *arXiv preprint arXiv:2303.02648*, 2023.

[23] T.-Y. Lin, M. Maire, S. Belongie, J. Hays, P. Perona, D. Ramanan, P. Dollár, and C. L. Zitnick, "Microsoft coco: Common objects in context," in *Computer Vision–ECCV 2014: 13th European Conference, Zurich, Switzerland, September 6-12, 2014, Proceedings, Part V 13*. Springer, 2014, pp. 740–755.

[24] K. Papineni, S. Roukos, T. Ward, and W.-J. Zhu, "Bleu: a method for automatic evaluation of machine translation," in *Proceedings of the 40th annual meeting of the Association for Computational Linguistics*, 2002, pp. 311–318.

[25] S. Banerjee and A. Lavie, "Meteor: An automatic metric for mt evaluation with improved correlation with human judgments," in *Proceedings of the acl workshop on intrinsic and extrinsic evaluation measures for machine translation and/or summarization*, 2005, pp. 65–72.

[26] C.-Y. Lin, "Rouge: A package for automatic evaluation of summaries," in *Text summarization branches out*, 2004, pp. 74–81.

[27] R. Vedantam, C. Lawrence Zitnick, and D. Parikh, "Cider: Consensus-based image description evaluation," in *Proceedings of the IEEE conference on computer vision and pattern recognition*, 2015, pp. 4566–4575.

[28] P. Anderson, B. Fernando, M. Johnson, and S. Gould, "Spice: Semantic propositional image caption evaluation," in *Computer Vision–ECCV 2016: 14th European Conference, Amsterdam, The Netherlands, October 11-14, 2016, Proceedings, Part V 14*. Springer, 2016, pp. 382–398.

[29] P. Anderson, X. He, C. Buehler, D. Teney, M. Johnson, S. Gould, and L. Zhang, "Bottom-up and top-down attention for image captioning and visual question answering," in *Proceedings of the IEEE conference on computer vision and pattern recognition*, 2018, pp. 6077–6086.

[30] O. Vinyals, A. Toshev, S. Bengio, and D. Erhan, "Show and tell: A neural image caption generator," in *Proceedings of the IEEE conference on computer vision and pattern recognition*, 2015, pp. 3156–3164.

[31] K. Xu, J. Ba, R. Kiros, K. Cho, A. Courville, R. Salakhudinov, R. Zemel, and Y. Bengio, "Show, attend and tell: Neural image caption generation with visual attention," in *International conference on machine learning*. PMLR, 2015, pp. 2048–2057.

[32] K. He, X. Zhang, S. Ren, and J. Sun, "Deep residual learning for image recognition," in *Proceedings of the IEEE conference on computer vision and pattern recognition*, 2016, pp. 770–778.

[33] A. Graves and A. Graves, "Long short-term memory," *Supervised sequence labelling with recurrent neural networks*, pp. 37–45, 2012.

[34] S. J. Rennie, E. Marcheret, Y. Mroueh, J. Ross, and V. Goel, "Self-critical sequence training for image captioning," in *Proceedings of the IEEE conference on computer vision and pattern recognition*, 2017, pp. 7008–7024.

[35] L. Guo, J. Liu, X. Zhu, P. Yao, S. Lu, and H. Lu, "Normalized and geometry-aware self-attention network for image captioning," in *Proceedings of the IEEE/CVF conference on computer vision and pattern recognition*, 2020, pp. 10 327–10 336.

[36] C. S. NagaDurga and T. Anuradha, "Attention-based comparison of automatic image caption generation encoders," in *Advances in Micro-Electronics, Embedded Systems and IoT: Proceedings of Sixth International Conference on Microelectronics, Electromagnetics and Telecommunications (ICMEET 2021), Volume 1*. Springer, 2022, pp. 157–167.

[37] C. L. Chowdhary, A. Goyal, B. K. Vasnani *et al.*, "Experimental assessment of beam search algorithm for improvement in image caption generation," *Journal of Applied Science and Engineering*, vol. 22, no. 4, pp. 691–698, 2019.

[38] Z. C. Lipton, J. Berkowitz, and C. Elkan, "A critical review of recurrent neural networks for sequence learning," *arXiv preprint arXiv:1506.00019*, 2015.

[39] K. Cho, B. Van Merriënboer, C. Gulcehre, D. Bahdanau, F. Bougares, H. Schwenk, and Y. Bengio, "Learning phrase representations using rnn encoder-decoder for statistical machine translation," *arXiv preprint arXiv:1406.1078*, 2014.

[40] A. Vaswani, N. Shazeer, N. Parmar, J. Uszkoreit, L. Jones, A. N. Gomez, Ł. Kaiser, and I. Polosukhin, "Attention is all you need," *Advances in neural information processing systems*, vol. 30, 2017.

[41] S. Ren, K. He, R. Girshick, and J. Sun, "Faster r-cnn: Towards real-time object detection with region proposal networks," *Advances in neural information processing systems*, vol. 28, 2015.

[42] A. Karpathy and L. Fei-Fei, "Deep visual-semantic alignments for generating image descriptions," in *Proceedings of the IEEE conference on computer vision and pattern recognition*, 2015, pp. 3128–3137.

# Optimizing the Production of Valuable Metabolites using a Hybrid of Constraint-based Model and Machine Learning Algorithms: A Review

Kauthar Mohd Daud[1], Ridho Ananda[2], Suhaila Zainudin[3],
Chan Weng Howe[4], Kohbalan Moorthy[5], Nurul Izrin Binti Md Saleh[6]
Center for Artificial Intelligence Technology, Faculty of Information Science and Technology,
Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor Malaysia[1,2,3]
Institut Teknologi Telkom Purwokerto, Indonesia[2]
UTM Big Data Centre, Faculty of Computing, Universiti Teknologi Malaysia,
81310 UTM Johor Bahru, Johor Malaysia[4]
Faculty of Computing, Universiti Malaysia Pahang Al-Sultan Abdullah, 26600 Pekan, Pahang Malaysia[5]
Faculty of Information and Communication Technology, Universiti Teknikal Malaysia Melaka,
Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia[6]

*Abstract*—The advances in genome sequencing and metabolic engineering have allowed the reengineering of the cellular function of an organism. Furthermore, given the abundance of omics data, data collection has increased considerably, thus shifting the perspective of molecular biology. Therefore, researchers have recently used artificial intelligence and machine learning tools to simulate and improve the reconstruction and analysis by identifying meaningful features from the large multi-omics dataset. This review paper summarizes research on the hybrid of constraint-based models and machine learning algorithms in optimizing valuable metabolites. The research articles published between 2020 and 2023 on machine learning and constraint-based modeling have been collected, synthesized, and analyzed. The articles are obtained from the Web of Science and Scopus databases using the keywords: "Machine learning", "flux balance analysis", and "metabolic engineering". At the end of the search, this review contained 13 records. This review paper aims to provide current trends and approaches in *in silico* metabolic engineering while providing research directions by highlighting the research gaps. In addition, we have discussed the methodology for integrating machine learning and constraint-based modeling approaches.

*Keywords—Flux balance analysis; genome-scale metabolic model; machine learning; metabolic engineering*

## I. INTRODUCTION

Microorganisms have been used in industrial sectors such as food processing, chemical manufacturing, pharmaceuticals, fermentation, and others. Advances in genome sequencing have resulted in several innovations that allow researchers to gain in-depth knowledge and information about an organism. One of these advancements is metabolic engineering, which reengineers the cellular function of an organism. In the 1990s, metabolic engineering was introduced to describe recombinant DNA technology for optimizing microbial activity [1]. Metabolic engineering aims to optimize the synthesis of desired metabolites by directing the metabolic flow and the fluxes toward the desired metabolites. The designs are categorized into two types: [1] targeting metabolic network components, such as gene/reaction knockout/knock-in, and [2]

enhancing the metabolic network by altering it using network reconstruction tools or incorporating new non-native pathways into the host.

Over the previous few decades, there has been a noticeable breakthrough, such as incorporating adenosylcobinamide phosphate biosynthesis from *Rhadobacter capsulatus* into the *E.coli* strain, which improves the vitamin $B_{12}$ to 307 $\mu g/g$ [2]. In another case, the yeast was engineered to improve the production of rubusoside and rebaudiosides, leading to 1368.6 $mg/L$ and 132.7 $mg/L$, respectively [3]. Although metabolic pathway optimization technologies have shown promise, an incomplete understanding of the connection between target cell phenotype and genotype impedes their further development. This results in the prevalent utilization of conventional trial-and-error methodologies and indirectly remains tedious, costly, and time-consuming.

Therefore, constraint-based modeling (CBM) approaches have been used to analyze organisms by providing significant phenotypic knowledge based on genotypic perturbations. CBM approaches, which include Flux Balance Analysis (FBA) and its variants (Minimization of Metabolic Adjustment, MoMA; Regulatory on/off minimization, ROOM; and Flux Variability Analysis, FVA), are used to reveal metabolic phenotypes by analyzing the optimality of an organism [4], [5]. However, a significant challenge in CBM is that the desired flux is not limited to a single solution due to biological network redundancy and complex genome-scale metabolic model (GSMM), thus permitting alternate optimum solutions. Furthermore, due to the intricacy and interdependence of components in the metabolic network, selecting appropriate and optimal reactions/genes for knockout is difficult, laborious, and time-consuming [6]. Hence, previous research has combined meta-heuristic optimization algorithms such as genetic algorithm (GA), differential search algorithms (DSA), flower pollination algorithm (FA), and others [7], [8], [9], [10].

With the recent advancement of high-throughput technology and the overwhelming amount of omics data, data collection has increased considerably, thus shifting the perspective

on molecular biology [11]. Although big data in biology enables data-driven science to comprehend complex biological systems and events, interpreting data is still complicated. Therefore, machine learning (ML) has been applied to deal with biological omics data for various applications such as prediction, classification, and discovery. The involvement of ML in the data shows a great potential to reveal hidden and detailed information in the data.

It has proven successful in diabetes disease prediction, optical character recognition, face identification, and others [12], [13], [14], [15]. ML is a set of algorithms to improve prediction accuracy by learning and analyzing the patterns from large experimental datasets. Recently, ML has been applied to increase the accuracy of the genotype-phenotype relationship by analyzing the integrated metabolic networks with regulatory or signaling networks. Furthermore, ML requires fewer parameters than other statistical or computation approaches, thus making them useful for various tasks, including predicting the impact of genetic perturbations, reconstructing phylogenetic trees, and others [16], [17].

This paper aims to review how ML techniques are applied in metabolic engineering, specifically to optimize the production of desired metabolites. The paper is organized as follows: Section II introduces the definition of metabolic engineering. Section III provides a brief on constraint-based modeling. Section IV discusses machine learning in metabolic engineering. Then, applications of machine learning in metabolic engineering have been described in Section V. After that results and discussion are provided in Section VI. In the last, the conclusion is given in Section VII.

## II. Metabolic Engineering

Each component in biological systems plays a vital role in biological processes and interacts with each other. Therefore, it is crucial to analyze the systems as a whole. The organism's function can be divided into three major biochemical pathways: gene regulatory, signal transduction, and metabolic networks. Gene regulatory involves a set of genes, proteins, and their regulatory mechanisms that determine the expression of the gene. Signal transduction networks communicate between and within cells by mediating, detecting, amplifying, and integrating various external and internal stimuli to govern and coordinate cellular activities. Meanwhile, the metabolic network is a series of biochemical reactions involving the transformation and modification of substrates into different products in which the enzymes act as catalysis agents. The metabolic network is essential in assessing a cell's biochemical and physiological properties. This research is mainly concerned with metabolic networks.

Advancements in genome sequencing have brought about many developments that allow biological researchers to have more profound knowledge and information about an organism. One of the developments is the establishment of metabolic engineering (ME), which allows the researchers to probe in detail the organizations of an organism, including the reactions, pathways, metabolites, and genes, and exploit the organisms for strain optimization. Metabolic engineering aims to optimize the metabolism of organisms by exploiting and manipulating their metabolic capabilities through modeling and, thus, generates economically and industrially viable organisms through
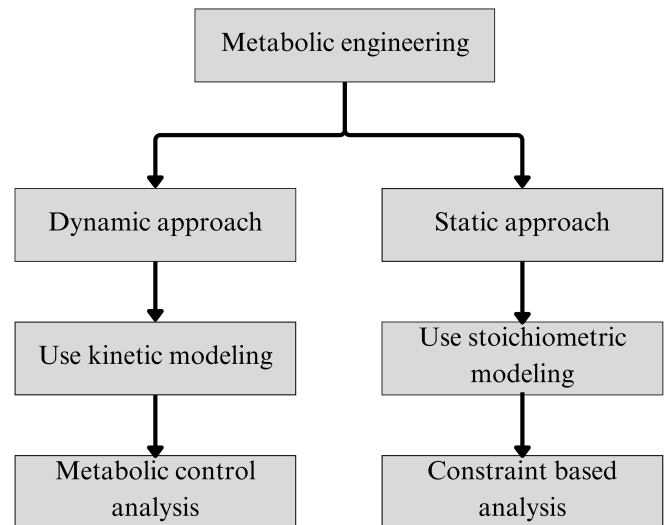


Fig. 1. Approaches in metabolic engineering.

optimization and predictive tools. In order to achieve this objective, it is necessary to adapt current metabolic engineering approaches by incorporating automated simulation techniques instead of relying on previous in vivo or in vitro investigations.

In order to exploit and manipulate the metabolic capabilities of an organism, the metabolic pathways within the cell need to be modeled. A model is a simplified system representation that allows the user to understand, predict, and control the system [18]. An organism can be modeled based on a dynamic or static approach. In ME, the metabolism of the target organism was represented in the mathematical model. Thus, the network's precise respective pathway or reactions that need to be manipulated and optimized can be identified. Various computational modeling approaches and algorithms have been developed and applied to aid the researchers [19]. Different approaches have been developed depending on the representations, as shown in Fig. 1.

The approaches in metabolic engineering can be divided into two, which are the dynamic approach and the static approach. Each approach varies in terms of metabolism representation, whereby the dynamic approach uses kinetic modelling and static approach uses a stoichiometric matrix to represent the metabolic network [20]. Furthermore, the difference between these two approaches is the model used. The dynamic approach uses a kinetic model, and the static approach uses a stoichiometric model or a metabolic network. Both of these models consist of different information and representations. The dynamic approach describes the changes in metabolite concentrations over time, while the static approach does not [21]. Table I defines the difference between the kinetic and the stoichiometric models.

In stoichiometric models, the biochemical reactions in the metabolic network are represented as a set of stoichiometric equations, whereby the elements of different metabolites in the metabolic network are denoted as stoichiometric coefficients in the stoichiometric matrix. Consequently, the intracellular metabolic fluxes can be determined at the steady state using the

TABLE I. DIFFERENCES BETWEEN THE KINETIC AND STOICHIOMETRIC MODELS

| Characteristics | Kinetic model | | Stoichiometric model |
|---|---|---|---|
| Definition | Describes changes in metabolite concentrations over time. | | Assumes the system is at steady-state conditions, where the concentrations of the metabolites are constant over time. |
| What information resides in the model? | 1)  Metabolites concentrations<br>2)  Kinetic parameters | | Stoichiometric information of all specified reactions and genes |
| How do they represent the model? | Ordinary differential equations (ODE) | | Linear equation |
| Size of the metabolic network for applicability | Small-scale metabolic network | | Large-scale metabolic network |
| How do they work? | It uses kinetic rate laws obtained from biochemical and mechanistic information. | | Imposes constraints and objective functions |
| Drawback | 1)  Requires many parameters<br>2)  Sometimes leads to uncertainty in the model prediction<br>3)  Not fully utilized in ME | | 1)  Lead to underdetermine system; the number of equations is larger than the number of variables<br>2)  Generate many possible solutions<br>3)  Solutions might not be unique |
| Time-consuming | High | | Low |
| Computational extensive | High | | Low |
| Accuracy | High | | Low |

mass balance constraints. However, stoichiometric models are often underdetermined and eventually lead to many possible non-unique solutions. Thus, the models require additional constraints to narrow the range of possible phenotypic solutions. These constraints may include physicochemical, biological, mass conservation, and thermodynamics. Stoichiometric models have been used to enumerate the fluxes in a metabolic network by employing an objective function. The main application of stoichiometric models is on metabolic networks, specifically in metabolic engineering strategies [7], [8], [22], [23].



Fig. 2. Unconstrained (a) and Constrained (b) Solution space.

## III. CONSTRAINT-BASED MODELING

The constraint-based method (CBM) is an approach to investigating the optimality of an organism by predicting and describing the metabolic phenotypes [24]. In CBM, constraints are applied to the systems, thus creating feasible flux distribution space. Different types of constraints can be categorized into physicochemical, topo-biological, environmental, and regulatory [25], [26]. These constraints can be expressed as equality or inequality constraints, as shown below, and have been reviewed by [26]. The equation that describes the incoming and outgoing fluxes accumulation for each metabolite in the metabolic network is described in 1.

$$\frac{d\mathbf{x}}{dt} = \mathbf{S} \times \mathbf{v} \qquad (1)$$

where $\mathbf{S}$ is the stoichiometric matrix of size $m \times n$ ($m$ is the number of metabolites and $n$ is the number of reactions), $\mathbf{X}$ is the $m$ concentration vector, and $v$ is the n flux vector. Each metabolite's production rate must equal the consumption rate

at the steady state. Therefore, the above equation is simplified to Eq. (2).

$$\mathbf{S} \times \mathbf{v} = \mathbf{0} \qquad (2)$$

The imposition of constraints will further reduce the number of allowable flux distributions and constraints taken upon the form in Eq. (3).

$$\alpha_i \leq v_i \leq \beta_i \qquad (3)$$

where $i$ is the length of $m$ reactions, $\alpha_i$ and $\beta_i$ are the lower and upper limits for the $i$ reaction, respectively. The values for $\alpha_i$ and $\beta_i$ are determined based on reactions' reversibility or irreversibility and measured uptake rates. These constraints may restrict specific phenotypes from existing in the solution space. Fig. 2 illustrates the differences between unconstrained and constrained solution space of feasible steady-state flux distributions.

As shown in Fig. 2, unconstrained steady-state solution space is underdetermined due to the ratio of reactions typically exceeding the number of metabolites. Eq. (1) provides a hyperplane that defines the allowable flux distributions. Considering different constraints, the solution space is limited to specific desired phenotypes. Therefore, CBM aims to describe and predict the desired phenotypes of an organism by describing the metabolic networks of an organism using the stoichiometric framework and a series of constraints. Despite the imposition of constraints and steady-state assumption, the solutions generated are not limited to a single solution. Instead, the solutions generated are limited to the desired phenotypes.

In order to solve the underdetermined system, the problem of measuring internal fluxes is solved using an optimization problem [28]. Thus, an objective function is defined, as illustrated in Fig. 3. Generally, an objective function is a biological assumption that an organism can be achieved. Then, linear optimization is used to find the solution that optimizes the desired objective function. Examples of objective functions include minimizing ATP production and nutrient uptake and maximizing growth rate. The most common objective function is growth rate since organisms maximize their growth after evolutionary pressures [29]. Referring to the above equations, Eq. 1 to 3, the objective function for maximizing the growth rate is mathematically represented by Eq. 4.

$$\max Z = v_{biomass} \qquad (4)$$

Generally, there are four CBM approaches - flux balance analysis (FBA), flux variability analysis (FVA), minimization of metabolic adjustment (MoMA), and regulatory on/off minimization (ROOM). Table II portrays the characteristics of the four CBM approaches and the applications that have been carried out.

As shown in Table II, FBA is a classical CBM method and has become one of the most common approaches researchers use [7], [8], [25], [30], [31]. Despite FBA's non-uniqueness due to the exclusion of regulatory and kinetic parameters, FBA excels in handling vast data within metabolic networks compared to other approaches, such as predicting higher steady states for

biological objectives such as growth rate and production rate. Moreover, despite the incompleteness of metabolic network models, FBA can still determine the organism's steady-state fluxes.

FVA employs linear programming to identify multiple biologically optimal solutions with the same objective value. These solutions are non-unique due to the metabolic network's ability to achieve the same objective value through different equivalent pathways, often represented by recessive phenotypes. Unlike FBA, which examines the distribution of flux within pathways, FVA focuses on determining the feasible ranges of minimum and maximum fluxes for each reaction. Meanwhile, MoMA employs quadratic programming to minimize the Euclidean distance on flux space between the wild-type and mutant, while ROOM predicts the post-genetic perturbation steady state of metabolic networks. In contrast to MoMA, ROOM identifies flux distributions that yield high-rate solutions while minimizing flux deviations between wild-type and mutant and preserving the linearity of fluxes based on experimental measurements [10], [32]. Additionally, ROOM can discover shorter alternative pathways for rerouting fluxes after genetic perturbations, employing mixed integer linear programming (MILP) to meet the same constraints as FBA.

## IV. Machine Learning in Metabolic Engineering

*In silico* metabolic engineering comprises computer simulations that predict and analyze an organism's metabolic network to improve the organism's cellular activities [8]. The improvement involves manipulating metabolic, signal, or regulatory networks. One approach to investigating the effects of genetic changes on metabolite synthesis is in silico reaction knockout modeling. The organism's behavior can be predicted through constraint-based modeling (CBM) methods by analyzing the effects of phenotypic and genotypic perturbations on the organisms.

High-throughput technologies such as gene sequencing, protein purification/quantification, mass spectrometry, and others have enabled a new era of biological information in which the amount of biological data has significantly expanded over
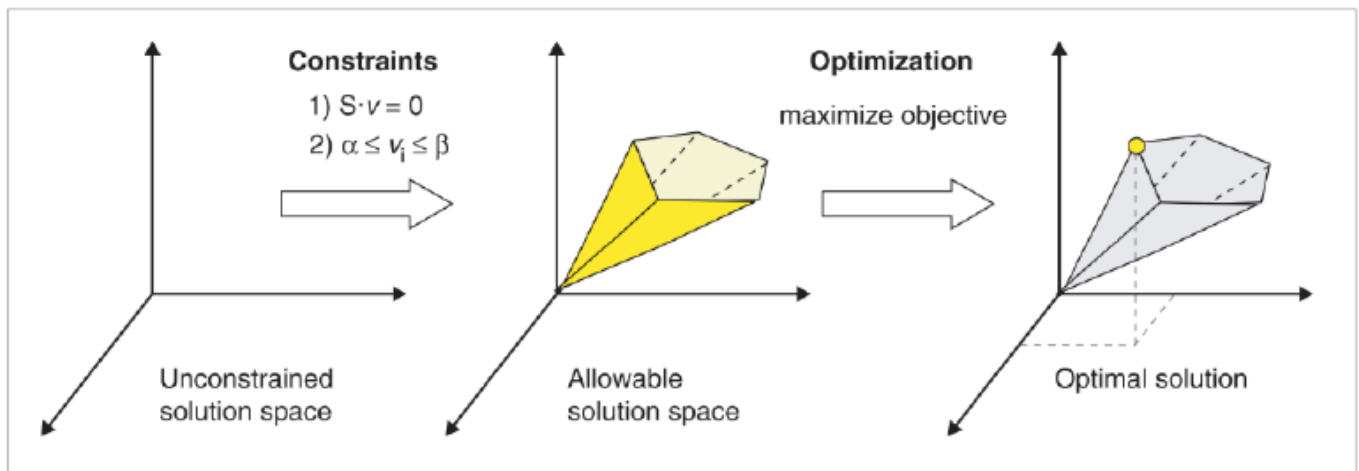


Fig. 3. The conceptual basis of CBM [27].

TABLE II. SUMMARY OF CONSTRAINT-BASED MODELING APPROACHES

| Characteristics | FBA | FVA | MoMA | ROOM |
|---|---|---|---|---|
| Purpose | Measure the optimal flux value | Measure the ranges of each flux | Compare the steady-state fluxes between mutant and wild-type | Minimize the number of significant flux changes between mutant and wild-type |
| Optimization model | Linear programming | Linear programming | Quadratic programming | Mixed-integer LP |
| Able to predict the lethality of genes? | Yes | No | No | Yes |
| Computational time | Short | Long | Long | Long |
| Size of model | Large | Large | Small | Large |
| Predicted solutions | Multiple optimal solutions | Assess the robustness of flux distribution | Transient metabolic states | The predicted solutions are nearer to the experimental data |

time. The various omics biological datasets, ranging from genomic to metabolomic and fluxomic, can provide direct insight into an organism's phenotype. An alternative approach is therefore needed to analyze and process large amounts of information quickly. Machine Learning (ML) has been increasingly used in metabolic engineering to replace human metabolic engineers [33], [34], [35]. Given its success in pattern recognition, model prediction, and others [36], [37], [38], [39], [40].

Machine learning (ML) is used to generate trial-and-error inferences and improve the predictions from data without a predefined set of rules. ML has been massively used in data analysis and typically allows applications to develop intelligently by understanding patterns in big data [1]. There are two types of ML based on data: labeled and unlabeled (Fig. 4). For the labeled data, algorithms learn from labeled training data to help predict the outcomes of unlabeled data. Meanwhile, unlabeled data use unsupervised learning to seek patterns and clusters in an unlabeled dataset. Examples of supervised learning algorithms include decision trees [41], support vector machines [42], and regression [43], whereas Principal Component Analysis (PCA) [44], [45] and K-means clustering [46] are unsupervised learning algorithms. Another ML type is reinforcement learning, in which the algorithm interacts with experience and learns to maximize the desired goal using experience, data, and trial-and-error interactions. Reinforcement learning does not need labeled input/output but focuses on balancing exploration and exploitation.

ML has recently played a significant role in biological research [16], [39]. These algorithms focus on model performance by training highly heterogeneous data. It is undoubtedly an opportunity to integrate ML algorithms with CBM models in various biological data sets such as gene expression, metabolites, phenotypes, and others [4], [47]. The application of ML in metabolic engineering will provide several benefits. First, ML can be used in various *in silico* metabolic engineering stages, from analyzing the metabolic flux data to designing optimal metabolic pathways. Second, the full integration of omics data, including genomic, transcriptomic, proteomic, and
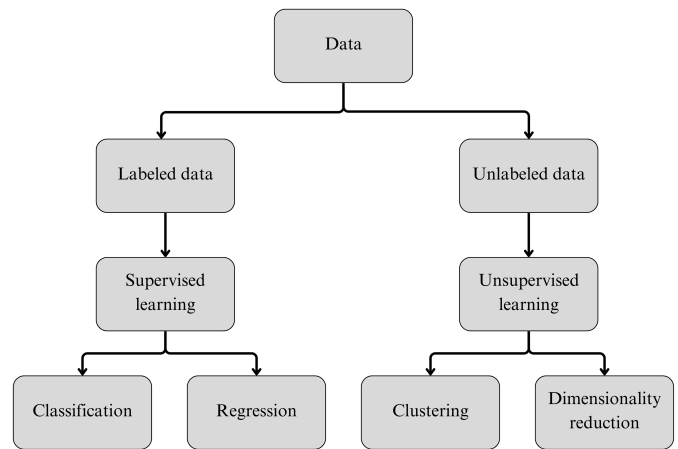


Fig. 4. Machine learning categories.

metabolomic data, is crucial for predicting the metabolic pathway as it provides valuable insight into biological networks [48]. Furthermore, via gene expression analysis using ML, the key regulators of a metabolic pathway can be identified based on the genetic perturbations on cellular metabolism.

Therefore, by merging machine learning with other computational tools in metabolic engineering, researchers may optimize cellular metabolism for enhanced production of biofuels, chemicals, and other essential molecules in a quick, cost-effective, and sustainable way. As shown in Fig. 5, the reactions and metabolites from GSMM are extracted and represented in a stoichiometric matrix. These datasets comprise instances (reactions and metabolites involved in the specific pathway). The coefficient in the stoichiometric matrix represents the knockout (coefficient one) and non-knockout reactions (coefficient zero) involved in that pathway. In this case, different combinations of knockout reactions are obtained. The training data, then, is used to train the chosen ML algorithms and predict the response of the test dataset. The responses
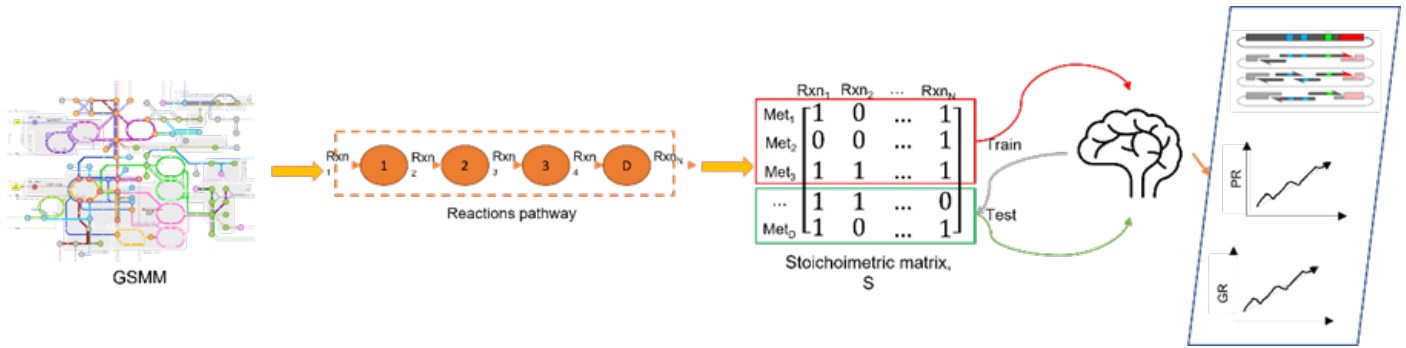
Fig. 5. Overview of the standard workflow of ML in ME.
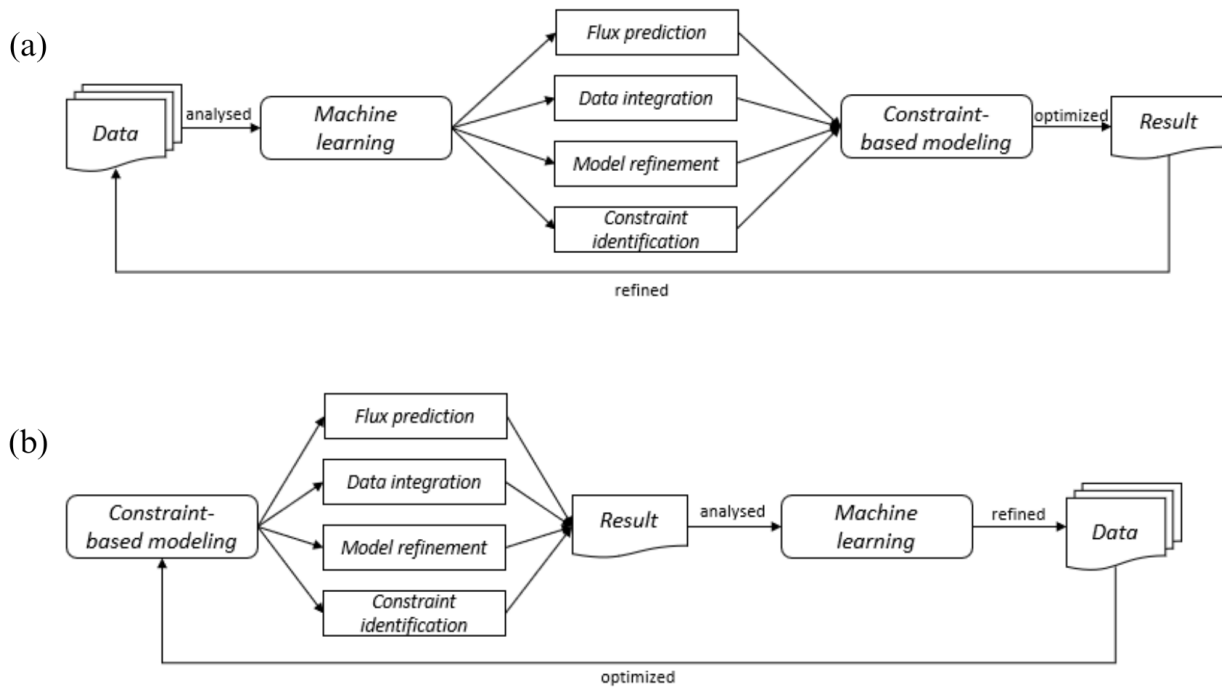


Fig. 6. Integration of machine learning and constraint-based modeling. (a) Refers to the ML as input to CBM, while (b) is CBM as input to ML).

include growth rate, product rate of desired metabolites, and different mutants with different combinations of knockout reactions.

According to [24], [49], the merging of ML and CBM can occur in three approaches. The first approach involves the inclusion of ML after CBM generates fluxomic data by predicting the growth conditions, cellular ML productivity, nutrient consumption, gene essentiality, or biomass concentration. The second approach uses a multi-omics data simplification process before entering the CBM process. The results of fluxomic data from CBM are then combined with the initial multi-omics data for the prediction process using a specific ML algorithm. The last approach uses ML on multi-omics data to get fluxomic data. This paper deduces that merging CBM with ML can occur in two ways, namely, ML as input to the CBM and CBM as input to the ML.

In the prior case, machine learning methods can improve metabolic models' accuracy and predictive power by predicting and refining metabolic models. The metabolic fluxes from omics data predicted using ML algorithms are input constraints for the metabolic model. Furthermore, ML can assist in identifying essential features (genes or reactions) for improving specific metabolite production. Considering that the metabolic model is complex, identifying crucial genes or reactions is essential while maintaining the viability of a cell. Meanwhile, in the post case, CBM can provide features, labels, and model selection to machine learning. Constraint-based approaches have been used to model the GSMM for simulating the phenotypic behavior after genotype perturbations. With the inclusion of machine learning methods, the selected features

from CBM can be used to train ML models for predicting the pathway activity, thus optimizing the metabolic model. Fig. 6 illustrates the integration of machine learning and constraint-based modeling approaches.

## V. Application of Machine Learning in Metabolic Engineering

An unprecedented amount of information has now been used to seek biological mechanisms at the molecular level. The recent advancement of high-throughput technologies has significantly boosted data collecting and fundamentally altered how people view molecular biology [50]. However, predicting bioproduction titers from microbial hosts has been challenging due to complicated interactions between regulatory networks, signaling, and metabolic networks [50]. There are several ways to carry out experiments concerning metabolic engineering. Machine learning, which has undoubtedly led to significant improvements in recent research and is expected to surge shortly, is a critical tool for analyzing, understanding, and exploiting omic data.

A novel approach for predicting yeast metabolome using machine learning based on quantitative proteomic data of kinase knockouts was presented by [51]. The results showed that the ML algorithm accurately predicts the metabolome with complex genetic modification. However, the study assumes that protein expression levels are proportional to changes in metabolic flux. Nevertheless, when post-transcriptional or post-translational modifications occur, the protein expression levels may differ and not proportionate to the changes in metabolic flux. Additionally, the dataset used is relatively small. Thus, expanding the dataset to include a broader range of genetic perturbations and experimental conditions could improve the generalizability of the ML models.

In another research, the integration of knowledge mining, genome-scale modeling, and ML for predicting the bioproduction of *Yarrowia lipolytica* has been proposed [50]. The proposed framework integrates different data, including genomics, metabolomics, and literature, to construct a knowledge-based and optimal GSMM. Then, ML algorithms are applied to predict bioproduction yields based on gene expression data and environmental conditions. They have successfully outperformed the traditional methods. However, the complexity of GSMM and lack of comprehensive knowledge may hinder accurate predictions. Thus, further development and validation are crucial to enhance its applicability and reliability.

Furthermore, [52] have proposed multi-omics data to analyze and characterize key molecular pathways and features essential for yeast growth based on different environmental conditions. The pipeline incorporates biological knowledge in the machine learning model to improve predictions. The proposed pipeline outperforms traditional ML methods and gives insight into the underlying biological mechanisms regulating cell growth. However, the pipeline has several limitations that need to be addressed. For instance, the pipeline relies on the quality and completeness of data sources, which may vary and be limited across different organisms.

A machine learning framework to assess microbial factories' performance was proposed by [1], which thos microbial are microorganisms that can produce various valuable compounds. Like [50], [52], the researchers proposed the integration of different data, including genomics, transcriptomics, metabolomics, and fermentation data. This integration framework is used to model the relationship between genetic and environmental factors and the production of target compounds. The proposed framework uses feature selection, regression, and classification algorithms to predict yields, identify genetic targets for strain engineering, and optimize the conditions. Although the proposed framework successfully demonstrated promising results, however, the framework relies on the availability of data sources. Furthermore, the complexity of metabolic networks and the lack of kinetic transcriptional or genomics data may affect the accuracy of prediction and strain engineering.

In addition, Tachibana and his colleagues prepared a study on Green Fluorescent Protein (GFP) extracted from engineered Escherichia coli. They conducted using Deep Neural Network (DNN) [53]. Before being assessed by machine learning to assign the GFP intensities into a reasonable range for analysis with the DNN technique, the GFP intensities were scaled down by five orders of magnitude. All machine learning methods utilized data from the yeast extract for double-validation calculations. The remaining data were divided into learning and test datasets for random cross-validation. DNNs were built using tanh activations and four hidden layers (200, 100, 50, and 20 units). The average Mean Squared Error (MSE), determined from the rearranged matrices for each variable, was used to measure representative importance in their study. Their research discovered that DNN showed high coefficients of determination and low MSE values.

Different ML algorithms, including random forest, support vector machine, and neural networks have been evaluated by [54], to assess their accuracy in predicting the phenotypic traits of three organisms: yeast, rice, and wheat. The study also investigates the impact of different feature selection methods and data preprocessing techniques on predictive performance. Based on the research, the authors found that combinations of ML algorithms and feature selection methods can achieve high accuracy in predicting phenotypic traits based on genetic data. In another domain, elastic net logistic regression has been proposed to determine the functional and structural brain alterations in female schizophrenia patients [55]. The study combines functional magnetic resonance imaging and diffusion tensor imaging to identify brain regions associated with the disease. The elastic net logistic regression selects relevant features and builds a predictive model. The study found that the model improves the accuracy of classifying the patients.

The developed framework or pipeline proposed by previous researchers demonstrates that machine learning can achieve high accuracy in predicting phenotypic traits based on genotypic perturbations. Moreover, multi-omics data integration has allowed ML algorithms to improve the accuracy of strain engineering in selecting the optimal genetic perturbations. However, there are some limitations and challenges that need to be addressed. Firstly, transcriptomic and genetic data availability is only limited to specific organisms. Thus, predicting and simulating genetic perturbations for less researched organisms is challenging. In addition, the complexity of metabolic networks, thus the complexity of integrated networks, may hinder the predictive capabilities and strain engineering. Therefore,

further development and validation, including biological validation, is needed to enhance ML's interpretability, robustness, and applicability in predicting phenotype changes.

Shimizu and Toya in 2021 experimented with evaluating the cellular performances of 13C- metabolic flux analysis using artificial gene deletion [56]. It is essential to understand the physiology of the metabolism in practical bioprocesses to evaluate the efficiency of the desired model. They stated that the quantitative imaging of microbial cells for metabolic engineering is enabled by metabolic flux analysis (MFA). The nonlinear least squares approach is used to compute metabolic fluxes. A mathematical model that includes carbon atom transfers and molecular mass balancing is provided. Based on the solution space, it is possible to calculate the best trajectory for a given growth and output rate. For the growth phase, the individual growth rate is kept at its highest level and shifted to the critical value, which produces the highest specific production rate.

### A. Combination of Unsupervised and Supervised Techniques

Moreover, many articles have reviewed the recent advances in model-assisted metabolic engineering, which aims to design and optimize the metabolic pathways of organisms to improve the production of desired metabolites [39], [57], [58]. Mainly, the review articles discussed the use of ML to assist in predicting the effects of genetic perturbations for integrated multi-omics data. Previously, metaheuristics optimization algorithms, such as Genetic Algorithm (GA), Differential Search Algorithm (DSA), flower pollination algorithm, Bee Algorithm, Particle Swarm Optimization (PSO), and others, have been used to improve the design of strain. The improved production of desired metabolites has proved the success of metaheuristic algorithms. However, with multi-omics data integration, the strain design becomes more challenging. Thus, using ML approaches is highly needed to enhance the accuracy of model predictions.

### B. Unsupervised Techniques

Unsupervised techniques identify patterns based on predetermined mathematical criteria (such as the number of clusters or variance independence). Large-scale biological datasets have been analyzed using both learning techniques, which have also been combined with FBA. For the unsupervised technique, Sahu et al. developed the "Split Lipids into Measurable Entities reactions" (SLIMEr) approach to model the lipids in genome-scale metabolic models in yeast [59]. SLIMEr later divides lipid components into acyl chain distributions and lipid classes using a mathematical framework, imposing limitations on both [59]. Subsequently, Sahu and his colleagues also established a framework to examine growth-related mechanisms of several S. cerevisiae strains by combining FBA with Multimodal Artificial Neural Networks [59]. The study was to use mechanistic knowledge to integrate data-driven ML techniques to overcome their "black-box" restriction in flux distributions. The framework was evaluated using 1,484 strains of *S. cerevisiae* with single gene knockouts. Growth rates were designated as constraints in pFBA. The study shows that Multimodal Artificial Neural Networks and FBA can train and predict the individual gene expression data for analyzing the flux distributions.

Jalili et al. (2021) performed cancer-specific metabolic signatures using Random forest classification with PCA and FBA [60]. For each cancer model, flux distributions were computed using FBA. After that, using PCA and Random Forests techniques, FBA-based characteristics were generated. PCA generates the variation of flux distributions in cancer models representing the response variables. Random Forests then employed these response variables to categorize crucial fluxes (which showed the impacted sub-cellular systems). Based on their study, the authors discovered that the pentose phosphate route, extracellular transport, mitochondrial transporters, fatty acid production, and other metabolic characteristics are the factors that distinguish between normal and abnormal cell metabolisms for the cancer model.

Meanwhile, unsupervised ML mainly creates clusterings or representations of the unlabeled dataset to reduce the dimensional complexity of data. Principal Component Analysis (PCA) and K-means clustering are examples of unsupervised ML. In ME, unsupervised ML techniques can be implemented to identify the appropriate and non-appropriate reactions involved in producing desired metabolites. Moreover, unsupervised clustering techniques have been used to distinguish different cell types, such as healthy and non-healthy, cancer and non-cancer markers, and stressed and non-stressed. Fig. 7 below illustrates the unsupervised methods in ME.

In another study, Barbosa and the team researched the effects of production factors such as sugar, nitrogen level, and fermentation temperature on wine quality in non-*Saccharomyces* yeasts [61]. The Exploratory Data Analysis (EDA) activity was enhanced by employing unsupervised machine learning on the entire experimental data set. Latent variable techniques, such as Principal Component Analysis, were used to investigate the responses of multivariate structure. Using agglomerative hierarchical clustering (AHC), 18 responses of natural groups were found. Consequently, the forward stepwise variable selection method is used to determine the input variables for the regression model. The study successfully found direct patterns between different production factors, signifying positive and negative correlations.

They stated that the correlation distance was used to identify clusters or groups of functionally related fermentation metabolites [61]. It was anticipated that the first principal component for the cluster-specific PCA models would explain the majority of the overall variability in the cluster due to highly correlated variables generating clusters. Upon completing PCA, supervised ML was also applied. They used a forward stepwise variable selection method to determine which input variables (experimental factors and their higher-order terms) should be included in the regression model. The stepwise selection technique involved picking and incorporating components one at a time. When there are no variables whose inclusion or exclusion from the model would result in a change in the model's explanatory power that is statistically significant, the method finally ends.

For unsupervised ML, they found that clear patterns of linked variables can be seen in the loading plots, such as those that cluster together or lie in the other direction, signifying positive and negative correlations, respectively, as in Fig. 8. This exploratory PCA analysis supports the necessity to investigate the modular structure of the answers in more detail
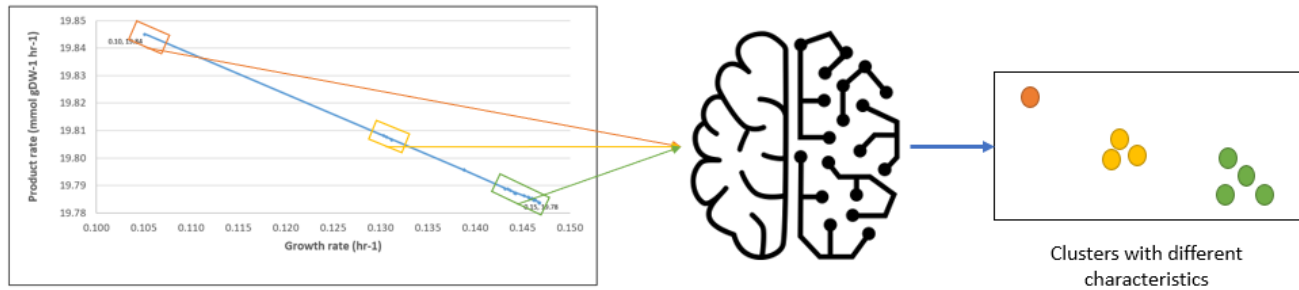
Fig. 7. Unsupervised ML in ME.
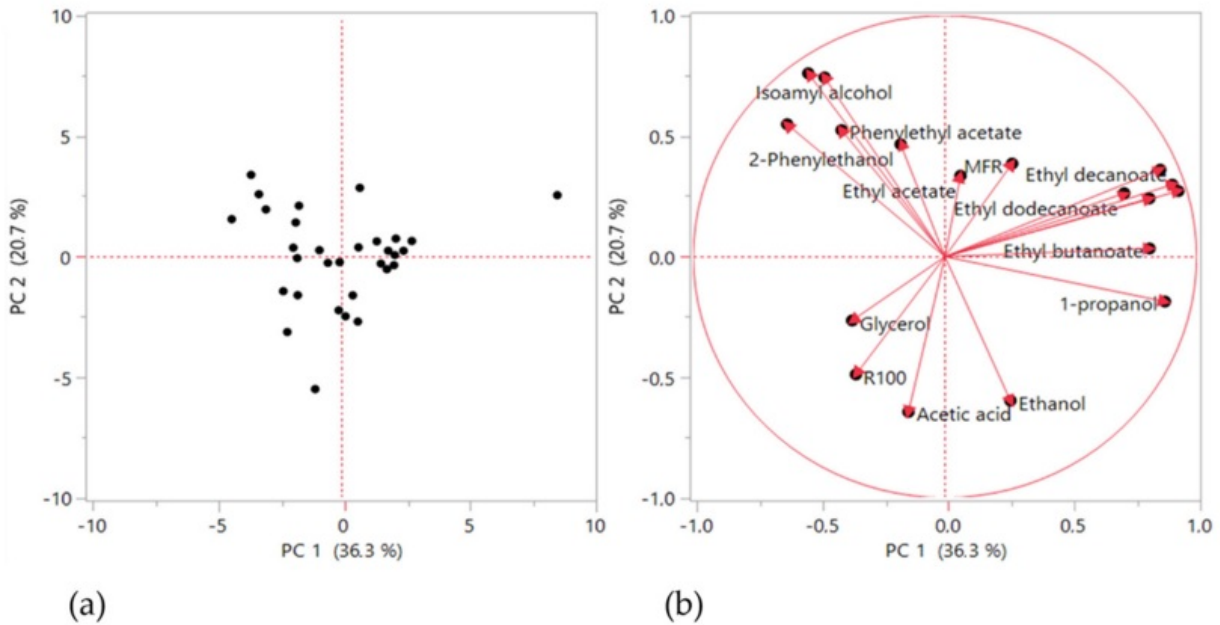


Fig. 8. Result using PCA. a) Scores plot, b) Loading plot [61].

and to identify the linked responses' natural building blocks. In order to uncover the natural blocks or clusters of variables, they implemented an agglomerative hierarchical variable-clustering approach (AHC). As a result, the variables are closer to each other, thus reducing the agglomeration distances [61]. For supervised ML, the considerable changes seen in the exploratory analysis section are confirmed by the modeling results utilizing main effects, second-order interactions, and quadratic terms, indicating the critical influence of the parameters on the fermentation process.

## VI. RESULT AND DISCUSSION

The first activity of this review is collecting the references. We first searched the Scopus and Web of Science databases with the keywords "Machine learning", "Flux balance analysis", and "Metabolic engineering" to find relevant literature in recent years. Then, we filtered for references related to the integration between ML and CBM from the results obtained.

After searching the keywords "Machine learning", "Flux balance analysis", and "Metabolic engineering", 223 research studies were extracted through automatic search from Scopus and Web of Science databases. Of the majority of these 223 studies, 32 were duplicate studies and review papers and thus were eliminated from the list. Based on the title, abstracts, and keywords, the remaining 191 research studies were examined, and 90 studies were excluded. Next, the remaining 101 studies were further selected, in which papers published from 2020 to 2023 were selected and left with 13 studies.

Then, the selected relevant references are synthesized. Table III illustrates the synthesis results of 13 relevant studies in the sources. In the table, 17 machine learning approaches are integrated into constraint-based modeling, namely, binary classifier, random forest, PCA, SVM, KNN, Decision tree, gradient tree boosting, DNN, CNN, t-SNE, ensemble learning, kMeans, lasso, multiview neural network, regularized logistic regression, ANN, and reinforcement learning. Out of those 13 studies, only two use the kinetic model, whereas most use the stoichiometric model. Since the stoichiometric model does

TABLE III. SUMMARY OF SELECTED RELEVANT STUDIES

| ID | Title | Year | Model | CBM | ML | Purpose | Strategy | Ref. |
|---|---|---|---|---|---|---|---|---|
| S1 | Prediction of gene essentiality using machine learning and genome-scale metabolic models | 2022 | S | FBA | Binary classifier | Improves the identification of the essential genes | 1 | [31] |
| S2 | Identifying metabolic shifts in Crohn's disease using' omics-driven contextualized computational metabolic network models | 2023 | S | FBA | Random forest | Identify biomarkers for Crohn's disease | 1 | [62] |
| S3 | Genome-scale modeling of Chinese hamster ovary cells by hybrid semi-parametric flux balance analysis | 2022 | S | FBA | PCA | Integrate parametric and non-parametric constraints for reducing the search space and improve the prediction of FBA | 2 | [29] |
| S4 | Computational Framework for Machine-Learning-Enabled C-13 Fluxomics | 2022 | S | MFA | SVM, KNN, decision tree, random forest, gradient tree boosting, DNN | Predict the flux ratio based on solvability and feature screening | 2 | [63] |
| S5 | Machine learning-guided evaluation of extraction and simulation methods for cancer patient-specific metabolic models | 2022 | S | FBA | CNN, t-SNE | Identify the biological features based on cancer patient-specific GEMs | 1 | [64] |
| S6 | Integrated knowledge mining, genome-scale modeling, and machine learning for predicting Yarrowia lipolytica bioproduction | 2021 | S | FBA | Ensemble learning | Reconstruct Yarrowia lipolytica GSM to improve organic acids' productions. | 2 | [50] |
| S7 | Integration of machine learning and genome-scale metabolic modeling identifies multi-omics biomarkers for radiation resistance | 2021 | S | FBA | Ensemble learning | Identify biomarkers that are associated with radiation resistance | 1 | [65] |
| S8 | In silico Design for Systems-Based Metabolic Engineering for the Bioconversion of Valuable Compounds From Industrial By-Products | 2021 | S | FBA | Random forest | Improve the production of glycerol by integrating transcriptomics data with metabolic network | 1 | [39] |
| S9 | A Hybrid Flux Balance Analysis and Machine Learning Pipeline Elucidates Metabolic Adaptation in Cyanobacteria | 2020 | S | rFBA | PCA, kMeans, Lasso | Identify the key cross-omics features | 1 | [66] |
| S10 | A mechanism-aware and multiomic machine-learning pipeline characterizes yeast cell growth | 2020 | S | pFBA | Multiview neural network | Improve the prediction of phenotypic traits of interest. | 1 | [52] |
| S11 | A biochemically-interpretable machine learning classifier for microbial GWAS | 2020 | S | popFVA | PCA, regularized logistic regression | Estimate the functional effects of genetic-associated alleles | 1 | [67] |
| S12 | A Machine Learning Approach for Efficient Selection of Enzyme Concentrations and Its Application for Flux Optimization | 2020 | K | FBA | PCA, ANN | Select the optimized enzyme concentration for optimal yield | 1 | [68] |
| S13 | Strain design optimization using reinforcement learning | 2022 | K | FBA | Reinforcement learning | Improve production of L-tryptophan | 1 | [69] |

Note : S represents the stoichiometric model; K represents the kinetic model; 1 represents CBM as input to ML; 2 represents ML as input to CBM.

not require intracellular experimental parameters, which are hardly known, stoichiometric models are more favorable for biologists to exploit the detailed capabilities of cell metabolism and [70] outperform kinetic model when the dataset used has large networks [71]. Though kinetic models provide detailed quantitative descriptions of the processes involved in the systems, thus revealing a system's actual dynamic biological behavior, the kinetic model is only limited to the small-scale and newly curated metabolic network [25].

Meanwhile, flux balance analysis (FBA) is the most widely used model assessment method because FBA uses linear programming that is easier to apply than MoMA and ROOM, which use quadratic programming and mixed-integer linear programming. Moreover, although the solutions provided by FBA are non-unique as it does not consider regulatory and signal data, the existing metabolic networks are still incomplete [23]. Regardless of these imperfections, FBA can determine the steady-state fluxes of organisms and predict the optimal long-term evolved state of the cells. In contrast, MoMA and ROOM predict the immediate initial outcome of genetic manipulations. However, cells will evolve from a minimized flux distribution state to an FBA solution [4]. In other words, genetic manipulations will first lead to flux distribution predicted by MoMA and ROOM, eventually converging to a solution predicted by FBA.

TABLE IV. SUMMARY OF MODEL, ADVANTAGE, AND DISADVANTAGES OF MACHINE LEARNING BASED ON THE RELEVANT STUDIES

| ID | Dataset | Result | Disadvantage |
|---|---|---|---|
| S1 | GEMs of Escherichia coli | The proposed approach showed that will-type FBA solutions contain enough information to predict essentiality, without perturbation such as reaction or gene knockout. | There is no a standar strategy on machine learning utilized for essentiality prediction generally. |
| S2 | RISK cohort data, gene expression data for all mucosal terminal ileal biopsies. | A framework that is a potential to identify pathways of clinical relevance in Crohn's disease, discover of novel diagnostic biomarkers, and therapeutic targets. | There is the discrepancy in the generated metabolic models of Crohn's disease in both RISK-derived tissue and enteroids. |
| S3 | GEMs of Chinese hamster ovary (CHO) cells | The proposed hybrid FBA by involving the mechanistic and non-parametric constraints can efficiently reduce the solution space and improve the prediction result of FBA. | Need the experimental fluxes datasets with the guaranteed high accuracy. |
| S4 | 13 C fluxomics | The proposed approach is reliable for fluxomics method readily and applicable to high-throughput metabolic phenotyping. | Computationally expensive especially in the large-scale metabolic network. |
| S5 | Cancer patient-specific GEMs | The results show that tINIT and GIMME has the high performance, but FBA and pFBA has poor performance in cancer metabolism. | Computationally expensive especially in the large GEMs. |
| S6 | GEMs of Yarrowia Lipolytica | This study succeed in integrating knowledge mining, feature extraction, GEMs, and ML for predicting chemical titers in Yarrowia lipolytica. | This model can not capture biosynthesis bottlenecks, consequently, the predictability for low-performance strains is not optimal. |
| S7 | Transcriptomic and genomic datasets | GEMs from patient tumors generated from transcriptomic and genomic datasets. The proposed approach, namely integrating ML and the generated GEMs, can identify prognostic metabolite biomarkers and predict radiosensitivity for individual patients. | Need to collect a larger datasets with the guaranteed high quality. |
| S8 | GEMs of Escherichia coli and transcriptomics data | The proposed method, namely the combination of transcriptome, GEMs, and machine learning can improve the production rate of glycerol. | It does not involve other parameters that influence metabolic processes, such as enzyme, transcriptional regulation, and signaling. |
| S9 | GEMs of Synechococcus sp. PCC 7002, transcriptomics | The proposed approach, namely model-generated flux data, are potential for predicting the growth rates. | Depends on Important information such as the specific metabolite uptake constraints and the nutrient uptake rates that are difficult to obtain directly. |

TABLE IV. SUMMARY OF MODEL, ADVANTAGE, AND DISADVANTAGES OF MACHINE LEARNING BASED ON THE RELEVANT STUDIES–CONTINUED

| ID | Dataset | Result | Disadvantage |
|---|---|---|---|
| S10 | Model of Saccharomyces cerevisiae | The proposed framework, namely, a multimodal learning framework, is capable for undestanding and manipulating complex phenotypes and increasing the prediction accuracy. | It does not involve other parameters that influence metabolic processes, such as enzyme, transcriptional regulation, and signaling. |
| S11 | Dataset of drug-tested Mycrobacterium tuberculosis strains | The proposed approach, namely metabolic allele classifier (MACs), can predict antimicrobial resistance (AMR) phenotypes with accuracy on par with mechanism-agnostic ML. | Not suitable for microbial genome-wide association studies. |
| S12 | The input data of 121 balances of four enzymes in the upper part of glycolysis | The ANN algorithms usedto select the enzyme concentration for the upper part of glycolysis | The ANN algorithms that was used to select the enzyme concentration for the upper part of glycolysis could select the optimum enzyme concentrations, improve flux up to 63%, and decrease a cost up to 25%. |
| S13 | GEMs of Escherichia coli, k-ecoli457 and Saccharomyces cerevisiae | The proposed method, namely MARL, could optimize the L-tryptophan production in S. cerevisiae and specific metabolite in the k-ecoli457. MARL could also be used to optimize metabolic gene expression levels. | Its application is still restricted to the particular target enzymes. |

As for integrating machine learning with constraint-based models, most those relevant studies employed the first strategy in which biological insights from CBM are used as input to ML. Given the intricacy of biological data and certain biological phenomena or systems that cannot be comprehensively described and examined mechanistically. In the table, there are 10 studies utilized the first strategy to integrate ML into CBM. The task of ML in those studies are to identify, improve, estimate, and select. In identifying, ML have been applied to identify the essential genes [31], biomarker [65], [62], the biological features [64], and the key cross-omics features [66]. Then, the application of ML in the improving process are to improve the production of glycerol [39], the prediction of phenotypic [69], and the production of L-tryptophan [69]. At the rest, ML was applied in estimating the functional effect of genetic-associated aleles and selecting the optimized enzyme concentration for optimal yield.

Nevertheless, some research studies employ a second strategy in which ML analyzes multi-omics data for CBM model reconstruction. In this strategy, ML have useful in the reducing, predicting, and reconstructing processes. In reducing, PCA has been implemented by integrating parametric and nonparametric constraints for reducing the search space in order to improve the prediction of FBA [29]. Then, several machine learning approaches have been utilized in the predicting process to get the optimal flux ratio based on solvability and feature screening [63]. Meanwhile, for reconstructing, Ensemble learning has been applied to reconstruct GSMMs of Yarrowia lipolytica in order to improve organic acids' productions [50], where the reconstruction of GSMM involves multiple steps, including annotation, gap filling, and refinement.

Table IV provides results, dataset used, and disadvantages of the relevant studies from Table III. Based on the synthesis and analysis results obtained from the relevant studies, there are several potentials of ML to contribute in *in silico* metabolic engineering. Integrating ML in traditional algorithms, such as flux balance analysis, can improve the production of the desired metabolites and even promise to guide strain optimization based on hybrid models, namely, the mechanistic and data-driven models. Moreover, ML has given positive influences on the prediction results by involving several experimental data such as fluxomic, transcriptomic, metabolomic, and proteomic in the process of constraint-based modeling. Also, it has been shown that ML can construct GSM, predict the essential genes, reduce the dimensionality of cross-omics features, and study the pattern of omic data. Based on those potentials, ML needs to be considered in metabolic engineering processes using CBM.

## VII. CONCLUSION

The advancements in biology, bioinformatics, and computational tools have led to the development of efficient software for modifying organisms for industrial use. Furthermore, the successful reconstruction models of complex biological systems by integrating data from various molecular levels have yielded valuable insights into organisms, thus offering accurate insights into cell activities during organism perturbations. However, this integration can complicate the identification of near-optimal reaction knockouts due to complex biological networks. Therefore, machine learning (ML) and constraint-based modeling (CBM) are employed to facilitate and enhance prediction accuracy.

This review introduced different structure models for representing organisms' systems. Due to the traditional approaches that are costly and irreversible, constraint-based methods have been introduced to overfit the production of valuable metabolites. Though it provides near-optimal solutions, integrating

diverse omics data holds substantial promise in predicting the future state of computational biology systems. Over the coming decade, there will be a growing need for machine learning methods that can be effectively utilized and tailored for these large datasets. Therefore, machine learning methods were integrated into CBM methods to improve the reconstruction of GSMM and the prediction accuracy of genetic perturbations.

We also reviewed several algorithms and applications developed and their different strategies and approaches used in metabolic engineering. As mentioned before, the integration of ML and CBM can happen in two ways. The first way is to apply ML to the integrated biological networks in which ML will identify the essential and meaningful features using the classification technique (supervised ML). This step minimizes the solution space and reconstructs a reduced integrated network for modeling in CBM. The second way is to analyze simulation modeling results from CBM (unsupervised ML).

In conclusion, ML is a superior technique for identifying meaningful features and patterns, which can help reconstruct integrated biological networks that represent the true nature of a cell, thus improving the predictive capabilities of identifying near-optimal reactions knockout for optimizing the production rate of valuable metabolites and growth rates of mutants for industrial purposes.

## References

[1] T. Oyetunde, D. Liu, H. G. Martin, and Y. J. Tang, "Machine learning framework for assessment of microbial factory performance," *PLOS ONE*, vol. 14, no. 1, pp. 1–15, 01 2019. [Online]. Available: https://doi.org/10.1371/journal.pone.0210558

[2] H. Fang, D. Li, J. Kang, P. Jiang, J. Sun, and D. Zhang, "Metabolic engineering of escherichia coli for de novo biosynthesis of vitamin $b_{12}$," *Nature Communications*, vol. 9, no. 4917, 11 2018.

[3] Y. Xu, X. Wang, C. Zhang, X. Zhou, X. Xu, L. Han, X. Lv, Y. Liu, S. Liu, J. Li, G. Du, J. Chen, R. Ledesma-Amaro, and L. Liu, "De novo biosynthesis of rubusoside and rebaudiosides in engineered yeasts," *Nature Communications*, vol. 13, no. 3040, 2022.

[4] P. Rana, C. Berry, P. Ghosh, and S. S. Fong, "Recent advances on constraint-based models by integrating machine learning," *Current Opinion in Biotechnology*, vol. 64, pp. 85–91, 2020, analytical Biotechnology. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S095816691930117X

[5] C. Shene, P. Paredes, L. Flores, A. Leyton, J. A. Asenjo, and Y. Chisti, "Dynamic flux balance analysis of biomass and lipid production by antarctic thraustochytrid oblongichytrium sp. rt2316-13," *Biotechnology and Bioengineering*, vol. 117, no. 10, pp. 3006–3017, 2020. [Online]. Available: https://onlinelibrary.wiley.com/doi/abs/10.1002/bit.27463

[6] K. V. Presnell and H. S. Alper, "Systems metabolic engineering meets machine learning: A new era for data-driven metabolic engineering," *Biotechnology Journal*, vol. 14, no. 9, p. 1800416, 2019. [Online]. Available: https://onlinelibrary.wiley.com/doi/abs/10.1002/biot.201800416

[7] S. Mutturi, "Focus: a metaheuristic algorithm for computing knockouts from genome-scale models for strain optimization," *Mol. BioSyst.*, vol. 13, pp. 1355–1363, 2017. [Online]. Available: http://dx.doi.org/10.1039/C7MB00204A

[8] K. M. Daud, M. S. Mohamad, Z. Zakaria, R. Hassan, Z. A. Shah, S. Deris, Z. Ibrahim, S. Napis, and R. O. Sinnot, "A non-dominated sorting differential search algorithm flux balance analysis (ndsdsafba) for in silico multiobjective optimization in identifying reactions knockout," *Computers in Biology and Medicine*, vol. 113, pp. 1–13, 2019. [Online]. Available: 10.1016/j.compbiomed.2019.103390

[9] E. Iranmanesh, M. A. Asadollahi, and D. Biria, "Improving l-phenylacetylcarbinol production in saccharomyces cerevisiae by in silico aided metabolic engineering," *Journal of Biotechnology*, vol. 308, pp. 27–34, 2020. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0168165619309186

[10] K. Shabestary and E. P. Hudson, "Computational metabolic engineering strategies for growth-coupled biofuel production by synechocystis," *Metabolic Engineering Communications*, vol. 3, pp. 216–226, 2016. [Online]. Available: doi:10.1016/j.meteno.2016.07.003

[11] H. A. BRAHIM, M. BENLLARCH, N. BENHIMA, S. EL-HADAJ, A. METRANE, and G. BELBARAKA, "New real dataset creation to develop an intelligent system for predicting chemotherapy protocols," *International Journal of Advanced Computer Science and Applications*, vol. 14, no. 8, 2023. [Online]. Available: http://dx.doi.org/10.14569/IJACSA.2023.0140886

[12] B. A. Al-Hameli, A. A. Alsewari, S. S. Basurra, J. Bhogal, and M. A. H. Ali, "Diabetes disease prediction system using hnb classifier based on discretization method," *Journal of Integrative Bioinformatics*, vol. 20, no. 1, 3 2023.

[13] N. Casano, S. J. Santini, P. Vittorini, G. Sinatti, P. Carducci, C. M. Mastroianni, M. R. Ciardi, P. Pasculli, E. Petrucci, F. Marinangeli, and C. Balsano, "Application of machine learning approach in emergency department to support clinical decision making for sars-cov-2 infected patients," *Journal of Integrative Bioinformatics*, vol. 20, no. 2, p. 20220047, 2023. [Online]. Available: https://doi.org/10.1515/jib-2022-0047

[14] J. Memon, M. Sami, R. A. Khan, and M. Uddin, "Handwritten optical character recognition (ocr): A comprehensive systematic literature review (slr)," *IEEE Access*, vol. 8, pp. 142 642–142 668, 2020.

[15] H. Hairani and D. Priyanto, "A new approach of hybrid sampling smote and enn to the accuracy of machine learning methods on unbalanced diabetes disease data," *International Journal of Advanced Computer Science and Applications*, vol. 14, no. 8, 2023. [Online]. Available: http://dx.doi.org/10.14569/IJACSA.2023.0140864

[16] A. V. Colarusso, I. Goodchild-Michelman, M. Rayle, and A. R. Zomorrodi, "Computational modeling of metabolism in microbial communities on a genome-scale," *Current Opinion in Systems Biology*, vol. 26, pp. 46–57, 2021. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S2452310021000123

[17] J. Y. Lee, B. Nguyen, C. Orosco, and M. P. Styczynski, "Scour: a stepwise machine learning framework for predicting metabolite-dependent regulatory interactions," *BMC Bioinformatics*, vol. 22, no. 365, 7 2021.

[18] M. R. Antoniewicz, "A guide to metabolic flux analysis in metabolic engineering: Methods, tools and applications," *Metabolic Engineering*, vol. 63, pp. 2–12, 2021, tools and Strategies of Metabolic Engineering. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S1096717620301683

[19] P. Kumar, P. A. Adamczyk, X. Zhang, R. B. Andrade, P. A. Romero, P. Ramanathan, and J. L. Reed, "Active and machine learning-based approaches to rapidly enhance microbial chemical production," *Metabolic Engineering*, vol. 67, pp. 216–226, 2021. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S1096717621001087

[20] M. Rocha, P. Maia, R. Mendes, J. P. Pinto, E. C. Ferreira, J. Nielsen, K. R. Patil, and I. Rocha, "Natural computation meta-heuristics for the in silico optimization of microbial strains," *BMC Bioinformatics*, vol. 9, no. 499, 11 2008.

[21] J. K. Khanijou, H. Kulyk, C. Bergès, L. W. Khoo, P. Ng, H. C. Yeo, M. Helmy, F. Bellvert, W. Chew, and K. Selvarajoo, "Metabolomics and modelling approaches for systems metabolic engineering," *Metabolic Engineering Communications*, vol. 15, p. e00209, 2022. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S2214030122000189

[22] T. B. Alter, L. M. Blank, and B. E. Ebert, "Genetic optimization algorithm for metabolic engineering revisited," *Metabolites*, vol. 8, no. 2, 2018. [Online]. Available: https://www.mdpi.com/2218-1989/8/2/33

[23] A. Passi, J. D. Tibocha-Bonilla, M. Kumar, D. Tec-Campos, K. Zengler, and C. Zuniga, "Genome-scale metabolic modeling enables in-depth understanding of big data," *Metabolites*, vol. 12, no. 1, 2022. [Online]. Available: https://www.mdpi.com/2218-1989/12/1/14

[24] M. K. Khaleghi, I. S. P. Savizi, N. E. Lewis, and S. A. Shojaosadati, "Synergisms of machine learning and constraint-based modeling of metabolism for analysis and optimization of fermentation parameters," *Biotechnology Journal*, vol. 16, no. 11, p. 2100212, 2021. [Online]. Available: https://onlinelibrary.wiley.com/doi/abs/10.1002/biot.202100212

[25] K. M. Shreya Anand and P. Padmanabhan, "An insight to flux-balance analysis for biochemical networks," *Biotechnology and Genetic Engineering Reviews*, vol. 36, no. 1, pp. 32–55, 2020. [Online]. Available: https://doi.org/10.1080/02648725.2020.1847440

[26] N. D. Price, J. L. Reed, and B. O. Palsson, "Genome-scale models of microbial cells: evaluating the consequences of constraints," *Nature Reviews Microbiology*, vol. 2, pp. 886–897, 11 2004.

[27] J. L. Reed, T. D. Vo, C. H. Schilling, and B. O. Palsson, "An expanded genome-scale model of Escherichia coli K-12 (iJR904," *Genome Biology*, 2003.

[28] B. García-Jiménez, J. Torres-Bacete, and J. Nogales, "Metabolic modelling approaches for describing and engineering microbial communities," *Computational and Structural Biotechnology Journal*, vol. 19, pp. 226–246, 2021. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S2001037020305286

[29] J. R. C. Ramos, G. P. Oliveira, P. Dumas, and R. Oliveira, "Genome-scale modeling of chinese hamster ovary cells by hybrid semi-parametric flux balance analysis," *Bioprocess and Biosystems Engineering*, no. 45, pp. 1889–1904, 10 2022.

[30] S. Tsouka, M. Ataman, T. Hameri, L. Miskovic, and V. Hatzimanikatis, "Constraint-based metabolic control analysis for rational strain engineering," *Metabolic Engineering*, vol. 66, pp. 191–203, 2021. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S1096717621000392

[31] L. J. Freischem, M. Barahona, and D. A. Oyarzún, "Prediction of gene essentiality using machine learning and genome-scale metabolic models," *IFAC-PapersOnLine*, vol. 55, no. 23, pp. 13–18, 2022, 9th IFAC Conference on Foundations of Systems Biology in Engineering FOSBE 2022. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S240589632300006X

[32] D. Kenefake, E. Armingol, N. E. Lewis, and E. N. Pistikopoulos, "An improved algorithm for flux variability analysis," *BMC Bioinformatics*, vol. 23, no. 550, 12 2022.

[33] M. S. Alzboon and M. S. Al-Batah, "Prostate cancer detection and analysis using advanced machine learning," *International Journal of Advanced Computer Science and Applications*, vol. 14, no. 8, 2023. [Online]. Available: http://dx.doi.org/10.14569/IJACSA.2023.0140843

[34] N. A. A. Hassan, R. A. A. A. A. Seoud, and D. A. Salem, "Open information extraction methodology for a new curated biomedical literature dataset," *International Journal of Advanced Computer Science and Applications*, vol. 14, no. 7, 2023. [Online]. Available: http://dx.doi.org/10.14569/IJACSA.2023.0140783

[35] Q. Yin, X. Ye, B. Huang, L. Qin, X. Ye, and J. Wang, "Stroke risk prediction: Comparing different sampling algorithms," *International Journal of Advanced Computer Science and Applications*, vol. 14, no. 6, 2023. [Online]. Available: http://dx.doi.org/10.14569/IJACSA.2023.01406115

[36] B. Wingfield, S. Coleman, T. McGinnity, and A. Bjourson, "Robust microbial markers for non-invasive inflammatory bowel disease identification," *IEEE/ACM Transactions on Computational Biology and Bioinformatics*, vol. 16, no. 6, pp. 2078–2088, 2019.

[37] I. K. Nti, A. F. Adekoya, B. A. Weyori, and O. Nyarko-Boateng, "Applications of artificial intelligence in engineering and manufacturing: a systematic review," *Journal of Intelligent Manufacturing*, vol. 33, pp. 1581–1601, 4 2021.

[38] X. Lv, A. Hueso-Gil, X. Bi, Y. Wu, Y. Liu, L. Liu, and R. Ledesma-Amaro, "New synthetic biology tools for metabolic control," *Current Opinion in Biotechnology*, vol. 76, p. 102724, 2022. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0958166922000581

[39] A. E. Tafur Rangel, W. Ríos, D. Mejía, C. Ojeda, R. Carlson, J. M. Gómez Ramírez, and A. F. González Barrios, "In silico design for systems-based metabolic engineering for the bioconversion of valuable compounds from industrial by-products," *Frontiers in Genetics*, vol. 12, 2021. [Online]. Available: https://www.frontiersin.org/articles/10.3389/fgene.2021.633073

[40] J. Zhang, S. D. Petersen, T. Radivojevic, A. Ramirez, A. Perez-Manriquez, E. Abeliuk, B. J. Sanchez, Z. Costello, Y. Chen, M. J. Fero, H. G. Martin, J. Nielsen, J. D. Keasling, and M. K. Jensen, "Combining mechanistic and machine learning models for predictive engineering and optimization of tryptophan metabolism," *Nature Communications*, vol. 11, no. 4880, 9 2020.

[41] T. Islam, A. B. Akhi, F. Akter, M. N. Hasan, and M. A. Lata, "Prediction of breast cancer using traditional and ensemble technique: A machine learning approach," *International Journal of Advanced Computer Science and Applications*, vol. 14, no. 6, 2023. [Online]. Available: http://dx.doi.org/10.14569/IJACSA.2023.0140692

[42] R. Siddalingappa and S. Kanagaraj, "A novel ml approach for computing missing sift, provean, and mutassessor scores in tp53 mutation pathogenicity prediction," *International Journal of Advanced Computer Science and Applications*, vol. 14, no. 6, 2023. [Online]. Available: http://dx.doi.org/10.14569/IJACSA.2023.01406111

[43] A. Altaf, H. Mahdin, A. Mahmood, M. I. H. Ninggal, A. Altaf, and I. Javid, "Systematic review for phonocardiography classification based on machine learning," *International Journal of Advanced Computer Science and Applications*, vol. 14, no. 8, 2023. [Online]. Available: http://dx.doi.org/10.14569/IJACSA.2023.0140889

[44] S. Swetha, G. N. Srinivasan, and P. Dayananda, "A hybrid multiple indefinite kernel learning framework for disease classification from gene expression data," *International Journal of Advanced Computer Science and Applications*, vol. 14, no. 6, 2023. [Online]. Available: http://dx.doi.org/10.14569/IJACSA.2023.0140690

[45] F. Islam, M. H. Rahman, Nurjahan, M. S. Hossain, and S. Ahmed, "A novel method for diagnosing alzheimer's disease from mri scans using the resnet50 feature extractor and the svm classifier," *International Journal of Advanced Computer Science and Applications*, vol. 14, no. 6, 2023. [Online]. Available: http://dx.doi.org/10.14569/IJACSA.2023.01406131

[46] Y. Boutazart, H. Satori, A. R. A. M, M. Hamidi, and K. Satori, "Covid-19 dataset clustering based on k-means and em algorithms," *International Journal of Advanced Computer Science and Applications*, vol. 14, no. 3, 2023. [Online]. Available: http://dx.doi.org/10.14569/IJACSA.2023.01403105

[47] Z. Wang, X. Peng, A. Xia, A. A. Shah, Y. Huang, X. Zhu, X. Zhu, and Q. Liao, "The role of machine learning to boost the bioenergy and biofuels conversion," *Bioresource Technology*, vol. 343, p. 126099, 2022. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0960852421014413

[48] A. Antonakoudis, R. Barbosa, P. Kotidis, and C. Kontoravdi, "The era of big data: Genome-scale modelling meets machine learning," *Computational and Structural Biotechnology Journal*, vol. 18, pp. 3287–3300, 2020. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S2001037020304335

[49] M. K. Khaleghi, I. S. P. Savizi, N. E. Lewis, and S. A. Shojaosadati, "Synergisms of machine learning and constraint-based modeling of metabolism for analysis and optimization of fermentation parameters," *Biotechnology Journal*, vol. 16, no. 11, p. 2100212, 2021. [Online]. Available: https://onlinelibrary.wiley.com/doi/abs/10.1002/biot.202100212

[50] J. J. Czajka, T. Oyetunde, and Y. J. Tang, "Integrated knowledge mining, genome-scale modeling, and machine learning for predicting yarrowia lipolytica bioproduction," *Metabolic Engineering*, vol. 67, pp. 227–236, 2021. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S1096717621001130

[51] A. Zelezniak, J. Vowinckel, F. Capuano, C. B. Messner, V. Demichev, N. Polowsky, M. Mülleder, S. Kamrad, B. Klaus, M. A. Keller, and M. Ralser, "Machine Learning Predicts the Yeast Metabolome from the Quantitative Proteome of Kinase Knockouts," *Cell Systems*, vol. 7, no. 3, pp. 269–283.e6, Sep. 2018. [Online]. Available: https://linkinghub.elsevier.com/retrieve/pii/S2405471218303168

[52] C. Culley, S. Vijayakumar, G. Zampieri, and C. Angione, "A mechanism-aware and multiomic machine-learning pipeline characterizes yeast cell growth," *Proceedings of the National Academy of Sciences*, vol. 117, no. 31, pp. 18 869–18 879, Aug. 2020. [Online]. Available: https://pnas.org/doi/full/10.1073/pnas.2002959117

[53] S. Tachibana, T.-Y. Chiou, and M. Konishi, "Machine learning modeling of the effects of media formulated with various yeast extracts on heterologous protein production in escherichia coli," *MicrobiologyOpen*, vol. 10, no. 3, p. e1214, 2021. [Online]. Available: https://onlinelibrary.wiley.com/doi/abs/10.1002/mbo3.1214

[54] N. F. Grinberg, O. I. Orhobor, and R. D. King, "An evaluation of machine-learning for predicting phenotype: studies in yeast, rice, and wheat," *Machine Learning*, vol. 109, no. 2, pp. 251–277, Feb. 2020. [Online]. Available: http://link.springer.com/10.1007/s10994-019-05848-5

[55] Y. Wu, P. Ren, R. Chen, H. Xu, J. Xu, L. Zeng, D. Wu, W. Jiang, N. Tang, and X. Liu, "Detection of functional and structural brain alterations in female schizophrenia using elastic net logistic regression," *Brain Imaging and Behavior*, vol. 16, no. 1, pp. 281–290, Feb. 2022. [Online]. Available: https://link.springer.com/10.1007/s11682-021-00501-z

[56] H. Shimizu and Y. Toya, "Recent advances in metabolic engineering–integration of in silico design and experimental analysis of metabolic pathways," *Journal of Bioscience and Bioengineering*, vol. 132, no. 5, pp. 429–436, 2021. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S138917232100205X

[57] P. F. Suthers, C. J. Foster, D. Sarkar, L. Wang, and C. D. Maranas, "Recent advances in constraint and machine learning-based metabolic modeling by leveraging stoichiometric balances, thermodynamic feasibility and kinetic law formalisms," *Metabolic Engineering*, vol. 63, pp. 13–33, 2021. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S109671762030183X

[58] G. Zampieri, S. Vijayakumar, E. Yaneske, and C. Angione, "Machine and deep learning meet genome-scale metabolic modeling," *PLOS Computational Biology*, vol. 15, no. 7, pp. 1–24, 07 2019. [Online]. Available: https://doi.org/10.1371/journal.pcbi.1007084

[59] A. Sahu, M.-A. Blatke, J. J. Szymanski, and N. Topfer, "Advances in flux balance analysis by integrating machine learning and mechanism-based models," *Computational and Structural Biotechnology Journal*, vol. 19, pp. 4626–4640, 2021.

[60] M. Jalili, M. Scharm, O. Wolkenhauer, M. Damaghi, and A. Salehzadeh-Yazdi, "Exploring the metabolic heterogeneity of cancers: A benchmark study of context-specific models," *Journal of Personalized Medicine*, vol. 11, no. 6, 2021. [Online]. Available: https://www.mdpi.com/2075-4426/11/6/496

[61] C. Barbosa, E. Ramalhosa, I. Vasconcelos, M. Reis, and A. Mendes-Ferreira, "Machine learning techniques disclose the combined effect of fermentation conditions on yeast mixed-culture dynamics and wine quality," *Microorganisms*, vol. 10, no. 1, 2022. [Online]. Available: https://www.mdpi.com/2076-2607/10/1/107

[62] P. Fernandes, Y. Sharma, F. Zulqarnain, B. McGrew, A. Shrivastava, L. Ehsan, D. Payne, L. Dillard, D. Powers, I. Aldridge, J. Matthews, S. Kugathasan, F. M. Fernández, D. Gaul, J. A. Papin, and S. Syed, "Identifying metabolic shifts in Crohn's disease using 'omics-driven contextualized computational metabolic network models," *Scientific Reports*, vol. 13, no. 1, p. 203, Jan. 2023. [Online]. Available: https://www.nature.com/articles/s41598-022-26816-5

[63] C. Wu, J. Yu, M. Guarnieri, and W. Xiong, "Computational framework for machine-learning-enabled 13c fluxomics," *ACS Synthetic Biology*, vol. 11, no. 1, pp. 103–115, 2022, pMID: 34705423. [Online]. Available: https://doi.org/10.1021/acssynbio.1c00189

[64] S. M. Lee, G. Lee, and H. U. Kim, "Machine learning-guided evaluation of extraction and simulation methods for cancer patient-specific metabolic models," *Computational and Structural Biotechnology Journal*, vol. 20, pp. 3041–3052, 2022. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S2001037022002434

[65] J. E. Lewis and M. L. Kemp, "Integration of machine learning and genome-scale metabolic modeling identifies multi-omics biomarkers for radiation resistance," *Nature Communications*, vol. 12, no. 1, p. 2700, May 2021. [Online]. Available: https://www.nature.com/articles/s41467-021-22989-1

[66] S. Vijayakumar, P. K. S. M. Rahman, and C. Angione, "A Hybrid Flux Balance Analysis and Machine Learning Pipeline Elucidates Metabolic Adaptation in Cyanobacteria," *iScience*, vol. 23, no. 12, p. 101818, 2020. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S2589004220310154

[67] E. S. Kavvas, L. Yang, J. M. Monk, D. Heckmann, and B. O. Palsson, "A biochemically-interpretable machine learning classifier for microbial GWAS," *Nature Communications*, vol. 11, no. 1, p. 2580, May 2020. [Online]. Available: https://www.nature.com/articles/s41467-020-16310-9

[68] A. Ajjolli Nagaraja, P. Charton, X. F. Cadet, N. Fontaine, M. Delsaut, B. Wiltschi, A. Voit, B. Offmann, C. Damour, B. Grondin-Perez, and F. Cadet, "A machine learning approach for efficient selection of enzyme concentrations and its application for flux optimization," *Catalysts*, vol. 10, no. 3, 2020. [Online]. Available: https://www.mdpi.com/2073-4344/10/3/291

[69] M. Sabzevari, S. Szedmak, M. Penttilä, P. Jouhten, and J. Rousu, "Strain design optimization using reinforcement learning," *PLOS Computational Biology*, vol. 18, no. 6, pp. 1–18, 06 2022. [Online]. Available: https://doi.org/10.1371/journal.pcbi.1010177

[70] T. Hameri, G. Fengos, and V. Hatzimanikatis, "The effects of model complexity and size on metabolic flux distribution and control: case study in Escherichia coli," *BMC Bioinformatics*, vol. 22, no. 1, p. 134, Dec. 2021. [Online]. Available: https://bmcbioinformatics.biomedcentral.com/articles/10.1186/s12859-021-04066-y

[71] K. Tummler and E. Klipp, "The discrepancy between data for and expectations on metabolic models: How to match experiments and computational efforts to arrive at quantitative predictions?" *Current Opinion in Systems Biology*, vol. 8, pp. 1–6, 2018, • Regulatory and metabolic networks • Special Section: Single cell and noise. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S2452310017301920

# Wrapper-based Modified Binary Particle Swarm Optimization for Dimensionality Reduction in Big Gene Expression Data Analytics

Hend S. Salem, Mohamed A. Mead, Ghada S. El-Taweel
Department of Computer Sciences, Suez Canal University, Ismailia, Egypt

*Abstract*—Gene expression data has emerged as a crucial aspect of big data in genomics. The advent of high-throughput technologies such as microarrays and next-generation sequencing has enabled the generation of extensive gene expression data. These datasets are characterized by their complexity, fast data generation, diversity, and high dimensionality. Analyzing high dimensional gene expression data offers both challenges and opportunities. Computational intelligence and deep learning techniques have been employed to extract meaningful information from these enormous datasets. However, the challenges related to preprocessing, reducing dimensionality, and normalization continue to exist. This study explored the effectiveness of the Wrapper-based Modified Particle Swarm Optimization (WMBPSO) algorithm in reducing dimensionality of big gene expression data for Alzheimer's disease (AD) prediction, using the GSE33000 dataset. The reduced dataset was then used as input to a CNN-LSTM model for prediction. The WMBPSO method identified 4303 genes out of a total of 39280 genes as being relevant for AD. These genes were selected based on their discriminatory power and potential contribution to the classification task, achieving an accuracy score of 0.98. The performance of the CNN-LSTM model is evaluated using these selected genes, and the results were highly promising. The results of our analysis are 0.968 for mean cross-validation accuracy, 0.995 for AUC, and 0.967 for recall, precision, and F1 score. Importantly, our approach outperforms conventional feature selection methods and alternative machine and deep learning algorithms. By addressing the critical challenge of dimensionality reduction in gene expression data, our study contributes to advancing the field of AD prediction and underscores the potential for improved diagnosis and patient care.

*Keywords*—*Alzheimer disease; big gene expression; binary particle swarm optimization; deep learning; dimensionality reduction*

## I. INTRODUCTION

In the rapidly evolving landscape of genomics and bioinformatics, the emergence of gene expression data as a prime example of big data presents both opportunities and formidable challenges. Big data, characterized by its immense size and complexity, demands innovative approaches for efficient processing and analysis [1]. Gene expression data, in particular, involves measuring the activity levels of thousands of genes across various biological samples or conditions. This surge in data generation has been fueled by advances in high-throughput technologies, such as microarrays and next-generation sequencing, ushering in an era of information abundance [2]. The following are some key aspects of gene expression data as big data:

- Volume: gene expression data is typically charac-

terized by its sheer volume. Experiments can yield thousands to millions of data points, each representing the expression level of a specific gene in each sample. These large datasets require substantial storage and computational power to manage and analyze effectively [3].

- Variety: gene expression data comes in various formats, such as raw intensity values from microarrays or read counts from RNA sequencing experiments. Additionally, it often includes associated metadata, such as sample annotations, experimental conditions, and clinical information. The integration and analysis of these diverse data types add complexity to the big data challenge [4].

- Velocity: the generation of gene expression data can be incredibly fast due to high-throughput technologies. With the ability to generate a massive amount of data in a short time, there is a need to find new ways to process and analyze the data rapidly [5].

- Complexity: analyzing gene expression data involves complex statistical and computational techniques to identify differentially expressed genes, perform clustering and classification, and infer gene regulatory networks. The complexity of these analyses increases with the size of the dataset [6].

- High dimensionality: each gene expression dataset typically consists of multiple samples (e.g., individuals, cells, or tissues) and thousands of genes. As a result, the data becomes high-dimensional, making it challenging to analyze and interpret effectively [7].

- Diversity of data sources: gene expression data is collected from diverse sources, including different tissues, organs, cell types, and experimental conditions. Integrating data from multiple sources adds complexity to the analysis and requires sophisticated data processing techniques [8].

While these characteristics offer tremendous insights into biological processes, they also present formidable analytical challenges. In light of these challenges, our study sets out to address two pivotal research questions that drive the core of our investigation.

Research Question 1: How can we effectively tackle the inherent complexity and high dimensionality of big gene expression data, specifically in the context of Alzheimer's Disease (AD) prediction?

As gene expression data exhibit substantial volume, diverse formats, rapid generation, inherent complexity, high dimensionality, and diverse data sources, it becomes paramount to devise innovative approaches to streamline the analysis process.

Research Question 1: How can we harness the power of Particle Swarm Optimization (PSO) to enhance deep learning models for gene selection, thereby improving AD prediction?

To overcome the challenges posed by high-dimensional gene expression data, we seek to integrate PSO into the feature selection process of deep learning models. This integration aims to harness PSO's optimization capabilities to select the most relevant genes, ultimately enhancing the performance of AD prediction models.

Alzheimer's Disease (AD) prediction stands out as a compelling application of gene expression data analysis. AD is a complex neurodegenerative disorder marked by progressive cognitive decline and memory loss [9]. Early and precise AD prediction is pivotal for timely interventions and personalized treatment strategies, with gene expression datasets serving as invaluable resources for identifying potential biomarkers and elucidating the underlying molecular mechanisms. Leveraging deep learning models and Particle Swarm Optimization (PSO) holds great promise in enhancing AD prediction accuracy and selecting the most relevant genes associated with the disease [9].

Deep learning models, such as convolutional neural networks (CNNs) and recurrent neural networks (RNNs), have revolutionized diverse fields by excelling in complex tasks like image recognition, natural language processing, and speech synthesis [10] [11]. Their capacity to automatically extract intricate hierarchical representations from data makes them particularly well-suited for gene expression data analysis in AD prediction tasks [12]. However, the effectiveness of deep learning models hinges on the availability of high-quality features that encapsulate pertinent information from the input data.

Feature selection plays a pivotal role in identifying and extracting the most informative features, thereby mitigating computational complexity and enhancing model interpretability [13].

Nonetheless, gene expression datasets often grapple with high dimensionality, encompassing a multitude of genes that may not all be pertinent for AD prediction [14]. Feature selection methods aim to tackle this challenge by combining the merits of filter and wrapper approaches. Filter methods gauge genes based on their statistical relevance to AD, utilizing metrics such as correlation or mutual information. In contrast, wrapper methods assess gene subsets using specific prediction algorithms.

Among these feature selection techniques, PSO has gained traction as an optimization algorithm for identifying the optimal gene subset [15]. Inspired by social behavior, PSO simulates the collective movement of particles within a search space, with each particle representing a potential solution guided by its own best position and the swarm's best position [16].

PSO has demonstrated effectiveness in solving optimization problems, including gene selection for AD prediction, through efficient exploration of the search space and convergence toward promising solutions.

This study's primary objective is to combine the strengths of deep learning models and PSO-based feature selection to enhance feature selection efficiency and deep learning model performance. By integrating PSO into the feature selection process of deep learning models, these hybrid approaches aim to overcome the limitations of traditional feature selection techniques and unlock the full potential of deep learning architectures. The utilization of PSO for feature selection involves two main stages: initialization and iterative optimization [17]. In the initialization stage, the PSO algorithm initializes a population of particles, each representing a potential feature subset. These particles traverse the search space, evaluating their fitness based on a fitness function that quantifies feature subset quality. The iterative optimization phase entails updating particle positions and velocities based on their own best positions and the best position discovered by the swarm, continuing until a termination criterion is met [18].

The integration of deep learning models with PSO-based feature selection offers several advantages. Firstly, it reduces input data dimensionality, crucial for managing large-scale datasets and mitigating overfitting risk. Secondly, it enhances model interpretability by selecting a subset of features most relevant to the target task. Lastly, it augments deep learning models' generalization capability by focusing on discriminative features, potentially leading to superior overall performance.

Having outlined these research questions, our study provides comprehensive answers and innovative solutions. We introduce a gene selection method based on a wrapper-based binary PSO (WBPSO) for dimensionality reduction. This method identifies the optimal subset of genes relevant to AD. Additionally, we propose a hybrid convolutional neural network (CNN) and long short-term memory (LSTM) deep learning model for precise AD prediction. Our study investigates the effectiveness of this approach in improving gene selection efficiency and deep learning model performance across various tasks. Comprehensive experiments conducted on benchmark gene expression datasets allow us to compare our method with other gene selection techniques and validate its superiority.

The remainder of this paper is organized as follows: Section II offers an examination of previous research concerning feature selection techniques and their integration with machine and deep learning models for Alzheimer's Disease (AD) prediction. Section III outlines the materials and methods employed in our proposed approach. Section IV delves into the experimental setup and presents an analysis of the results obtained from our experiments. Section V provides the limitations of the study and some future directions. Lastly, in Section VI, we wrap up the paper by summarizing our discoveries, highlighting the most important findings, and specifying our contribution.

## II. Literature Review

This section provides an overview of various investigations concerning feature selection techniques and the prediction of Alzheimer's disease (AD) using machine and deep learning approaches with gene expression data. Each study is summarized and evaluated for its contributions and limitations.

Martinez et al. [19] introduced a methodology to identify AD-associated genes using decision trees, quantitative association rules, and hierarchical clustering. While this approach effectively detected genes with significant expression changes, its scalability was limited for large-scale datasets.

In their work, Park et al. [20] proposed a deep learning model for AD prediction by integrating gene expression and DNA methylation data. Although their model showed improved accuracy compared to traditional machine learning methods, it faced limitations, including a small sample size, potential overfitting, and a lack of benchmarking with logistic regression or other deep learning algorithms.

Sharma et al. [21] employed random forest and regularized regression models (specifically LASSO) to analyze microarray datasets across four brain regions. This approach aimed to identify genetic biomarkers for AD prediction, achieving high accuracy. However, it faced challenges in handling high-dimensional data and potential overfitting.

Chen et al. [22] highlighted the significance of differential network analysis to uncover AD-related genes using the JDINAC machine learning method. This method successfully identified differential networks associated with AD pathology, contributing to a better understanding of the disease.

Patel et al. [23] focused on differentiating individuals with AD from others using gene expression biomarkers in blood samples. While their XGBoost classification models achieved success, there was a need to improve sensitivity and establish a more specific blood signature for AD.

Bogdanovic et al. [24] emphasized proper experimental design and preprocessing techniques to analyze a large dataset. Their approach, based on XGBoost, achieved competitive performance and offered interpretability, highlighting the importance of explainable machine learning in AD diagnosis.

In [25], an autoencoder (AE) was employed to integrate DNA methylation and gene expression data for AD prediction. The approach demonstrated improved accuracy, addressing the challenges of high-dimensional, low-sample size datasets.

Mahendran et al. [26] developed a gene selection pipeline for AD, combining mRmR, WPSO, and Autoencoder methods. They used Bayesian Optimization to tune hyperparameters and achieved promising results.

Lee et al. [27] utilized three publicly available datasets to investigate AD-related genes and develop classifiers. Their approach demonstrated predictive performance, even across different datasets.

Kamal et al. [28] employed machine learning techniques to classify AD using both image and gene expression data. The CNN achieved high accuracy for image data, while SVC demonstrated accuracy for gene expression data, with the aid of LIME for interpretability.

Maj et al. [29] combined deep learning and machine learning techniques to analyze gene expression data in AD. Their study highlighted the potential of recurrent neural networks (RNNs) in modeling gene expression data, although limitations included sample size and sex-specific considerations.

Kim et al. [30] used the SpliceAI framework, based on a variant of convolutional neural networks (CNNs) called the residual CNN model, to predict Alzheimer's disease (AD)-specific nucleotide alteration sites in pre-messenger RNA (mRNA) sequences. They identified 14 splicing sites in the PLCG1 gene with single-nucleotide variants (SNVs) occurring at the same position in both humans and the AD mouse model cortex. The study's limitation lies in investigating only one gene and lacking comparison with existing models. Future studies should consider analyzing more genes and incorporating high-quality gene expression data for a comprehensive evaluation of model performance.

The work in [31], a deep learning model based on Wasserstein Generative Adversarial Networks (GANs) with a gradient penalty term was utilized to predict the virtual disease/molecular progression of Alzheimer's disease (AD) using gene expression data from a mouse AD model. The latent space interpolation of GANs was leveraged to describe pathological pathway cascades in AD progression. However, the study had limitations, including a small number of differentially expressed genes (DEGs) used for training data and a small sample size of gene expression profiles, which hindered drawing conclusive results. Additionally, the proposed model was not compared to existing models to demonstrate its performance, and future studies should consider incorporating more genes and high-quality augmentation data.

Xie et al. [32] introduced MLP-SAE, a deep learning regression model for predicting gene expression based on genetic variation. The model outperformed other methods, highlighting the potential of deep learning in genomics data analysis.

Alhenawi et al. [33] conducted a systematic review of feature selection methods for microarray data analysis, highlighting the prevalence of hybrid feature selection methods as a promising research direction.

The existing methods, while contributing significantly to AD prediction using gene expression data, face limitations ranging from scalability to interpretability. These limitations have created a notable research gap, particularly concerning high dimensionality and feature selection accuracy

In this paper, we introduce a novel gene selection method based on a wrapper-based binary Particle Swarm Optimization (PSO) algorithm (WBPSO). Our approach is designed to overcome the limitations of existing feature selection techniques by efficiently selecting informative genes for AD prediction. Furthermore, we extend our approach by integrating the selected genes into a hybrid convolutional neural network (CNN) and long short-term memory (LSTM) deep learning model. This integration aims to enhance model interpretability and significantly reduce dimensionality, potentially improving overall AD prediction performance.

Table I provides a summary of some recent research investigating the prediction of Alzheimer's disease (AD) through

the analysis of gene expression data, utilizing various gene selection (GS) techniques and machine and deep learning (ML) models.

## III. MATERIALS AND METHODS

This section presents the proposed method, a comprehensive account of the dataset employed, the preprocessing steps applied to the microarray dataset, and the techniques employed for gene selection and AD prediction. As illustrated in Fig. 1, the overall approach consists of four main components: Preprocessing, Gene Selection, AD Prediction, Performance Evaluation. Utilizing this framework enables the opportunity to create a powerful AD prediction system that merges deep learning models with wrapper-based feature selection method that is inspired by nature. This system leverages big gene expression dataset to produce precise and dependable predictions, ensuring accuracy and reliability. The following sections provide a comprehensive explanation of each individual component in the proposed approach.
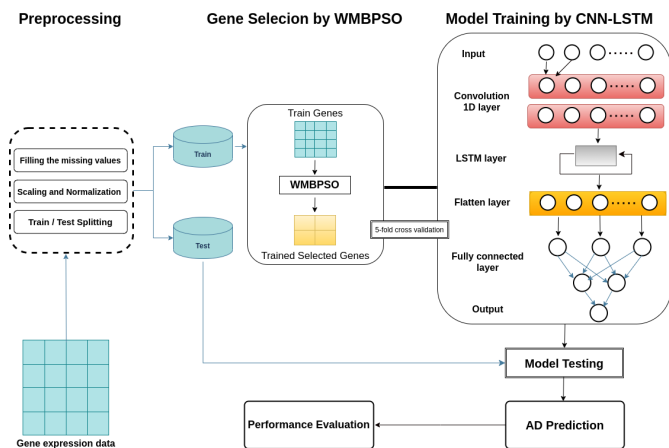


Fig. 1. The overall dimensionality reduction and AD prediction approach.

### A. Dataset

The dataset utilized in this study was obtained from the National Center for Biotechnology Information-Gene Expression Omnibus (NCBI-GEO) database [42]. Specifically, the dataset corresponds to the access number GSE33000. It comprises four DNA microarray data profiles, representing multiple tissues in the human brain. These profiles were collected from three distinct brain regions of AD patients: prefrontal cortex (PFC), visual cortex (VC), and cerebellum (CR). However, the focus of the GSE33000 dataset is exclusively on the PFC. In total, the dataset consists of 624 demented and non-demented control cases, each characterized by 39,280 genes.

### B. Preprocessing

To prevent training bias, it is crucial to normalize the input data within a specific range when training models using large channel values. The GSE33000 dataset is preprocessed by the following:

1) Filling the missing values (NaN) by using the mean Let $G$ is the set of genes and $C$ is the set of cases

that have value, and $C'$ is the complementary set of cases that are missing (denoted as NaN or NULL) For each case $ci$ : If the value of case $c_i$ in gene $g_j$ is missing, then its value is filled using the available values by the following formula:

$$m_{c_i,g_j} = \frac{\sum_{c_i \in C_{g_j}} v_{c_i,g_j}}{|C_{g_j}|} \tag{1}$$

where $m_{c_i,g_j}$ represents the missing value of case $i$ in gene $j$.

2) Scaling and Normalization: In this step we used the StandardScaler. In this scaler, the mean is subtracted from each sample and then scaled to have a unit variance. The data is re-scaled in a way that ensures it has a mean of 0 and a standard deviation of 1. The standard score $z$ of a sample $x$ is calculated using the formula:

$$z = (x - u)/s \tag{2}$$

Where $u$ represents the mean and $s$ denotes the standard deviation.

### C. Wrapper-based Modified Binary Particle Swarm Optimization(WMBPSO)

To address research question 1, which focuses on the utilization of Particle Swarm Optimization (PSO) for gene selection, we employ the Wrapper-based Modified Binary Particle Swarm Optimization (WMBPSO) algorithm. The Particle Swarm Optimization (PSO) algorithm is a metaheuristic optimization technique inspired by the social behavior of bird flocking or fish schooling in a search space. For gene selection, the PSO algorithm seeks to find the optimal set of genes that will maximize the performance of the deep learning model. In order to do this, the PSO algorithm assigns each gene a weight, and then iteratively updates these weights based on the fitness of the current solution. Binary Particle Swarm Optimization (BPSO) is a variant of PSO that is specifically designed for binary optimization problems. The Wrapper-based Modified Binary Particle Swarm Optimization (WMBPSO) algorithm includes some modifications compared to the base BPSO algorithm. Fig. 2 depicts the flowchart of the WMBPSO, and the following are the key modifications:

TABLE I. SUMMARY OF SOME RECENT RESEARCH INVESTIGATING THE PREDICTION OF AD THROUGH THE ANALYSIS OF GENE EXPRESSION DATA, UTILIZING VARIOUS GS TECHNIQUES AND MACHINE AND DEEP LEARNING MODELS

| Study | Dataset | GS Method | Model | Performance |
|---|---|---|---|---|
| [20] | GSE33000 GSE44770 GSE80970 | DMP DEG | DNN | Acc = 82.3% |
| [34] | Proteomic | Belief Network | DBN | Acc > 90% |
| [35] | GSE33000 GSE5281 GSE122063 GSE97760 | NONE | SVM | AUC=0.879 |
| [36] | GSE33000 ADNI | Importance Scores | PINNet | AUC=0.97 F1=0.96 |
| [37] | GSE33000 GSE44770 GSE44771 GSE44768 | Chi squared ANOVA MI | SVM | ACC=0.975 AUC=0.972 |
| [38] | GSE33000 | DEG LASSO | SVM-RFE RF | AUC=0.954 |
| [39] | GSE63060 GSE63061 | LASSO | SVM | Acc= 0.781 AUC=0.859 |
| [40] | GSE63061 DCR | RFE | RF | Acc=0.657 AUC= 0.724 |
| [26] | GSE5281 | mRmR WPSO Autoencoder | IDBN | Sensitivity=94.54 Specificity=96.17 Accuracy=96.78 FMeasure=95.09 |
| [27] | GSE63060 GSE63061 ADNI | CFG CFG CFG | DNN SVM DNN | AUC=0.874 AUC=0.804 AUC=0.657 |
| [41] | GSE63060 GSE63061 | LASSO | SVM | AUC=0.859 Acc= 0.781 |
| [40] | GSE5281 | t-test | SVM | AUC=0.894 |
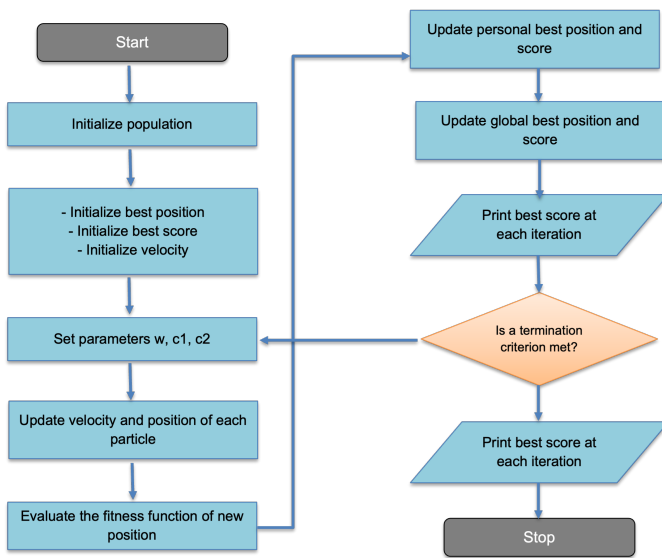


Fig. 2. WMBPSO flowchart.

1) Initialize the population: Each particle represents a subset of genes to be selected.
Let $X = [x_1, x_2, ..., x_n]$ be the binary feature vector

for a particle, where $n$ is the total number of features. The value of each feature $x_i$ is either 0 (not selected) or 1 (selected).

2) Evaluate the fitness: Train a CNN-LSTM model using the selected subset of features (genes). Evaluate the fitness of each particle based on the performance metrics (accuracy, F1, AUC, recall, precision) achieved by the model on the AD prediction task.

3) Update the velocity of each particle using Eq. 3:

$$v(t + 1) = w * v(t) + c_1 * r_1 * (pbest - x(t)) \\ + c_2 * r_2 * (gbest - x(t)) \quad (3)$$

Here, $v(t)$ represents the current velocity, $w$ is the inertia weight, $c_1$ and $c_2$ are acceleration coefficients, $r_1$ and $r_1$ are random numbers, $pbest$ represents the personal best position (best subset of genes) for the particle, and $gbest$ represents the global best position (best subset of genes) among all particles.

4) Update the position of each particle by rounding the sigmoid output of the velocity using the equation:

$$x(t + 1) = \text{round}\left(\frac{1}{1 + \exp(-v(t + 1))}\right) \quad (4)$$

5) Apply boundary conditions to ensure that the positions of particles (gene subsets) stay within the valid

range of feature selections.

6) Evaluate the fitness of each particle based on the performance of the CNN-LSTM model using the updated feature subset. Update the personal best position (*pbest*) and fitness for each particle if its fitness improves. Update the global best position (*gbest*) and fitness if any particle achieves a better fitness than the current global best.

### D. Hybrid Convolutional Neural Network (CNN) and Long Short-Term Memory (LSTM)

To answer research question 2, which revolves around enhance deep learning models for gene selection, thereby improving AD prediction, we incorporate the architectures of Convolutional Neural Networks (CNN) and Long Short-Term Memory (LSTM) along with WMBPSO for AD prediction into our model. The CNN-LSTM model combines the CNN and LSTM architectures to process both spatial and temporal information in the gene dataset.

*1) Convolutional Neural Network (CNN):* A Convolutional Neural Network (CNN) is a powerful deep learning technique that has found extensive use in various applications, including image classification, object detection, speech recognition, computer vision, video analysis, and bioinformatics [43]. Unlike traditional neural networks, CNNs are characterized by their deep architecture, incorporating multiple layers [44]. These networks utilize weights, biases, and nonlinear activation functions to process input data effectively. At its core, a CNN consists of convolutional layers, pooling layers, and fully connected layers, forming a comprehensive architecture for feature extraction and classification tasks [45]. Fig. 3 portrays the basic structure of CNN network.
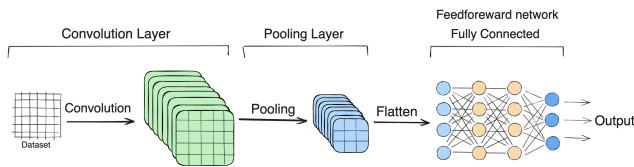


Fig. 3. Basic structure of CNN model.

The CNN's core operation is convolution, which employs convolution kernels to perform convolutions on the inputs. It differs from fully connected structures by leveraging information from adjacent areas of the data matrix. Sparse connections and weight sharing significantly reduce the parameter matrix size. The pooling layer creates feature maps through averaging or taking the maximum value, compressing features and mitigating overfitting. CNN allows for constructing multi-layer convolution and pooling operations [46]. Deeper layers extract more abstract features. These abstract features are then merged using a fully connected layer. Finally, classification and regression problems can be addressed using softmax or sigmoid activation functions. In our case, we utilize one-dimensional convolution in CNN to effectively extract spatial features from gene expression data. The convolution layer operates as a filter and subsequently undergoes activation through a non-linear activation function, as described in Eq. 5:

$$a_{i,j} = f\left(\sum_{m=1}^{M}\sum_{n=1}^{N} w_{m,n} \cdot x_{i+m,j+n} + b\right) \quad (5)$$

where $a_i, j$ is the activation, $f$ denotes a non-linear function, $w_m, n$ represents the m×n matrix of convolution kernel weight, $x_{i+m,j+n}$ refers to the activation of the upper neurons and connected to the neuron $(i,j)$, and $b$ represents the bias value. In this study, the convolutional layers utilize rectified linear units (ReLU) for computing the feature maps. The non-linear function associated with ReLU is defined in Eq. 6:

$$\sigma(x) = \max(0, x) \quad (6)$$

Where $x$ is the input value and 0 is a threshold. The ReLU activation function takes an input $x$ and computes the output as follows: If $x$ is greater than or equal to 0, the function returns $x$. If $x$ is negative, the function returns 0. In essence, the ReLU activation function linearly activates the positive part of the input, while any negative input is turned off (outputting 0).

*2) Long Short-Term Memory (LSTM):* An LSTM network belongs to the class of recurrent neural networks (RNNs) and offers significant advantages over traditional RNNs, allowing for faster learning and addressing issues such as vanishing and exploding gradients [46]. By incorporating memory blocks and employing a cell state, an LSTM network can effectively store and retrieve long-term information. This is achieved through the utilization of input, forget, and output gates, which enable the network to retain relevant past data and connect it with the present inputs. As a result, LSTM networks are capable of solving complex tasks that were challenging for earlier RNN architectures, making them a valuable tool in various applications [43]. The cell state is the main component of LSTM, which involves three essential processes. The initial step entails deciding the type and quantity of information to be eliminated from the cell state, accomplished through the forget gate. Subsequently, the input gate determines the new information to be incorporated into the cell state. Lastly, the output gate determines the specific information to be outputted.
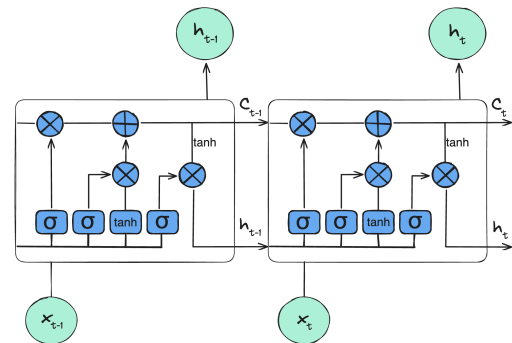


Fig. 4. Typical design of LSTM model.

The LSTM model enhances the original short-term memory unit, represented by $h_t$, by introducing a memory unit $C_t$

to preserve long-term memory or the cell state. In Fig. 4, we observe that an LSTM unit receives three inputs at each time step: the current input $x_t$, the previous state $C_{t-1}$, and the previous output $h_{t-1}$. Notably, both $x_t$ and $h_{t-1}$ are simultaneously utilized as inputs for three gates. The LSTM network follows a specific update process, which can be summarized in Eq. 7:

$$f_t = \sigma(W_f \cdot [h_{t-1}, x_t] + b_f) \tag{7}$$

$$i_t = \sigma(W_i \cdot [h_{t-1}, x_t] + b_i) \tag{8}$$

$$\tilde{C}_t = \tanh(W_c \cdot [h_{t-1}, x_t] + b_c) \tag{9}$$

$$C_t = f_t \times C_{t-1} + i_t \times \tilde{C}_t \tag{10}$$

$$o_t = \sigma(W_o \cdot [h_{t-1}, x_t] + b_o) \tag{11}$$

$$h_t = o_t \times \tanh(C_t) \tag{12}$$

where, $W_f$, $W_i$, $W_c$, $W_o$ represent the coefficient matrices, $b_f$, $b_i$, $b_c$, $b_o$ are the matrices of bias, $\sigma$ is a sigmoid activation function, $f_t$ denotes the forget gate, which regulates the amount of previous memory to be discarded. In contrast, the input gate denoted as $i_t$ determines the amount of new memory $\tilde{C}_t$ to be stored in long-term memory.

### E. Performance Evaluation

In this research, we assessed the performance of our approach using the test dataset. We employed five metrics to evaluate the predictive capability: Accuracy, Recall, Precision, F1 score, and AUC. These metrics quantify the number of true positives (TP), true negatives (TN), false positives (FP), and false negatives (FN), and the following are the details of each metric.

- Accuracy: is a metric that quantifies the ratio of correct predictions $(TP + TN + FP + FN)$ made by the predictor or classifier to the total number of data points $(TP + TN)$ in a dataset. The accuracy metric is calculated using Eq. 13 as follows:

$$Accuracy = \frac{TP + TN}{TP + FN + TN + FP} \tag{13}$$

- Recall (also known as sensitivity): measures the ability of a model to correctly identify positive instances out of all the actual positive instances. It quantifies the proportion of true positives that are correctly predicted. The recall metric is calculated by using Eq. 14 as follows:

$$Recall = \frac{TP}{TP + FN} \tag{14}$$

- Precision (also known as positive predictive value): measures the proportion of true positives out of all the instances that the model predicted as positive. It

focuses on the accuracy of the positive predictions.The precision metric is calculated by using Eq. 15:

$$Precision = \frac{TP}{TP + FP} \tag{15}$$

- F1 score: is a metric that combines precision and recall into a single value. It provides a balanced measure of a model's performance by taking into account both false positives and false negatives. The F1 score is calculated by using Eq. 16:

$$F1 = 2 \cdot \frac{precision \cdot recall}{precision + recall} \tag{16}$$

- AUC: stands for Area Under the Curve provides a single scalar value that summarizes the overall performance of a binary classification model in terms of its ability to rank and discriminate between positive and negative instances. Once the Receiver Operating Characteristic (ROC) curve is created by plotting the true positive rate (TPR), which is synonymous with sensitivity or recall, on the y-axis, and the false positive rate (FPR), calculated as (1 - specificity), on the x-axis , the AUC is computed as the area under this curve.

## IV. RESULTS AND DISCUSSION

For the experimental work, the code was executed using Python version 3.8.10. The libraries employed were Keras, Tensorflow, and Scikit-learn. The experimental setup included an Intel® CoreTM i5-8250U CPU @ 1.60 GHz, 8 GB of main memory, and a 64-bit OS running Ubuntu 20.04.1 LTS. In this study, the performance of WMBPSO algorithm was investigated for dimensionality reduction of big gene expression data in the context of AD prediction. The reduced dataset was then used as input for a CNN-LSTM model for prediction.

### A. Dimensionality Reduction using WMBPSO

The WMBPSO gene selection technique identified a total of 4303 genes as being relevant for AD prediction, achieving an accuracy score of 0.98. These genes were selected based on their discriminatory power and potential contribution to the classification task. This dimensionality reduction significantly improved model performance. The dimensionality reduction achieved through WMBPSO has profound implications. It not only improved AD prediction accuracy but also streamlined the feature set, making it more interpretable.

### B. Comparative Analysis of Gene Selection Methods

We conducted a comparative analysis of the WMBPSO-based approach with three commonly used methods for gene selection: the lasso-based approach, the ANOVA method, and a hybrid ANOVA-lasso-PSO method. The performance of the lasso approach compared to WMBPSO-CNN-LSTM is depicted in Fig. 5. The lasso approach achieved an accuracy of 0.920 and an AUC of 0.915. The F1 score, recall, and precision for the lasso approach were 0.929, 0.961, and 0.90, respectively. Fig. 6 reports the scores of ANOVA method, it achieved an accuracy of 0.89 and an AUC of 0.88, which are lower than those obtained by the WMBPSO approach.
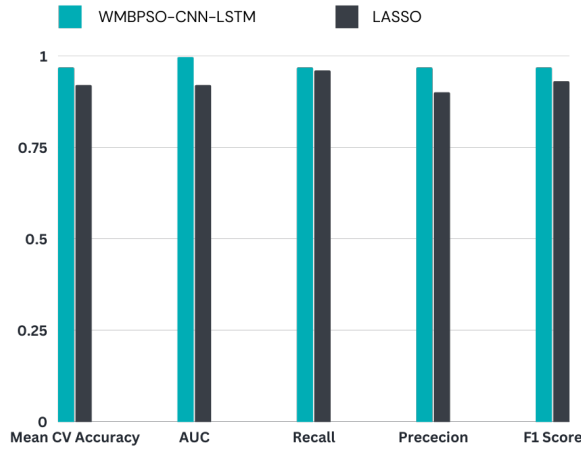
Fig. 5. Comparison of the proposed WMBPSO with lasso method.
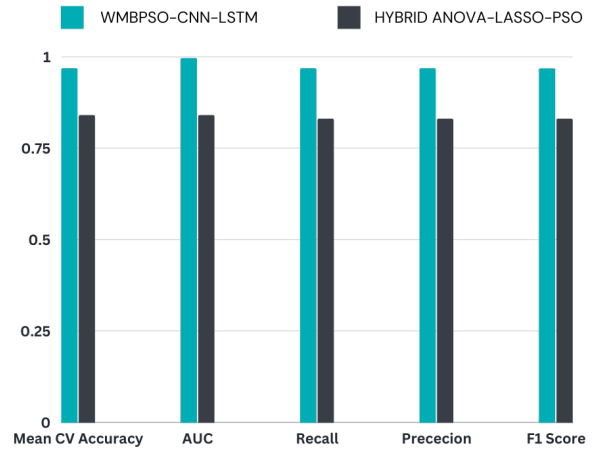


Fig. 7. Comparison of the proposed WMBPSO with hybrid anova-lasso-WMBPSO method.
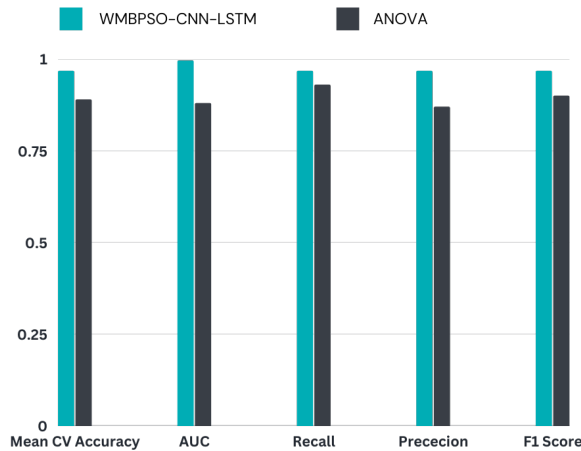


Fig. 6. Comparison of the proposed WMBPSO with anova method.

F1, recall, and precision scores were 0.90, 0.93, and 0.87, respectively.

Fig. 7 describes the performance of the hybrid ANOVA-LASSO-PSO method. This method achieved an accuracy of 0.84 and an AUC of 0.84. Also, the method obtained the value 0.83 for F1 score, recall, and precision. The comparison between the WMBPSO-based approach and the other gene selection methods highlights the effectiveness of the WMBPSO approach and showed competitive performance with a strong AUC score.

## C. AD Prediction with WMBPSO-CNN-LSTM

The CNN-LSTM model, trained with the selected genes, yielded highly promising results. The performance of the CNN-LSTM model is evaluated using these selected genes, and the results were highly promising. The results of our analysis are presented in Fig. 8. To train the CNN-LSTM model for AD prediction, we utilized a cross-validation approach with k = 5 folds to further assess the robustness of

the model. The model was trained over 10 epochs, with a batch size of 32. The mean cross-validation (CV) accuracy, calculated over multiple iterations, was found to be 0.968. This value indicates a consistently high level of accuracy across different folds of the dataset, reinforcing the reliability of the proposed model. Moreover, the area under the curve (AUC) was used to evaluate the model's performance in terms of its ability to discriminate between AD and non-AD cases. The AUC value obtained was 0.9958, suggesting a high level of discrimination power. Additional performance metrics were computed, the recall value was 0.9677; this indicates that the model effectively identified a high percentage of AD cases. Similarly, the precision value was also 0.9677. This indicates that the model made a high percentage of correct positive predictions. Also, the F1 score was found to be 0.9677. This value indicates a balanced trade-off between precision and recall, demonstrating the model's ability to achieve both high precision and high recall simultaneously.
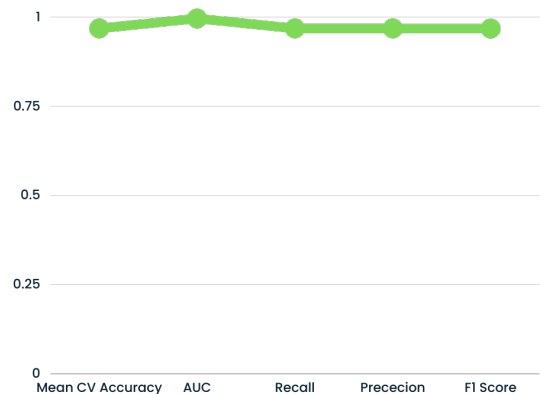


Fig. 8. Performance metrics of the proposed WMBPSO-CNN-LSTM approach.

To evaluate the superiority of the CNN-LSTM model

in combination with the WMBPSO-based gene selection method, we conducted a performance comparison between the WMBPSO-CNN-LSTM model and two other deep learning models, WMBPSO-RNN and WMBPSO-CNN, which also utilized the WMBPSO algorithm for gene selection. For the CNN model, as shown in Fig. 10, the results obtained were 0.94, 0.93, 0.95, 0.93, and 0.94 for mean cross-validation accuracy, AUC, recall, precision, and F1 score, respectively. Fig. 9 portrays the performance of WMBPSO-RNN. The results obtained were 0.84, 0.89, 0.84, 0.85, and 0.85 for mean cross-validation accuracy, AUC, recall, precision, and F1 score, respectively. The comparison among the three models
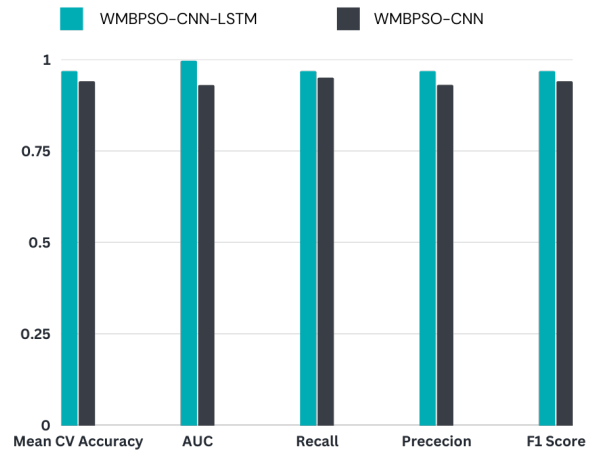


Fig. 10. Comparison of the proposed WMBPSO-CNN-LSTM model with CNN model.
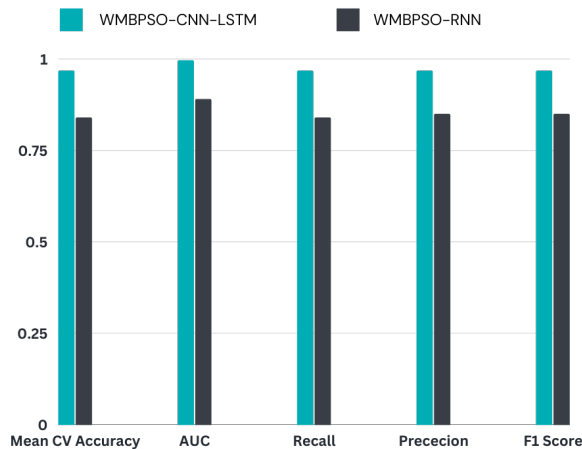


Fig. 9. Comparison of the proposed WMBPSO-CNN-LSTM model with RNN model.

TABLE II. PERFORMANCE EVALUATION VALUES OF DIFFERENT MACHINE LEARNING MODELS COMPARED TO THE PROPOSED WMBPSO-CNN-LSTM

| Model | Recall | Precision | F1 Score | Accuracy |
|---|---|---|---|---|
| Logistic Regression | 0.97 | 0.91 | 0.94 | 0.93 |
| Boosted Random Forest | 0.83 | 0.86 | 0.84 | 0.83 |
| Decision Tree | 0.82 | 0.79 | 0.80 | 0.78 |
| SVM | 0.95 | 0.93 | 0.94 | 0.93 |
| KNN | 0.80 | 0.87 | 0.83 | 0.82 |
| MLP | 0.66 | 0.97 | 0.79 | 0.80 |
| Guassian NB | 0.72 | 0.80 | 0.76 | 0.74 |
| ANN | 0.97 | 0.86 | 0.91 | 0.90 |
| **WMBPSO-CNN-LSTM** | **0.97** | **0.97** | **0.97** | **0.97** |

Further comparisons with various machine learning methods are presented in Table II.

The remarkable performance of the CNN-LSTM model highlights its effectiveness in handling the reduced dataset. This suggests that by effectively managing dimensionality, we can harness the full potential of deep learning models. In conclusion, according to the findings of this study, the WMBPSO-CNN-LSTM model demonstrated superior performance compared to the WMBPSO-CNN, WMBPSO-RNN, as well as other machine learning models and prevalent feature selection techniques in reducing dimensionality and predicting Alzheimer's Disease using big gene expression data. The WMBPSO-CNN-LSTM model exhibited outstanding AUC, higher accuracy, F1 score, recall, and precision. These results underscore its superior ability to capture relevant features and patterns related to big gene expression data.

*D. Implications and Suggestions*

Our findings carry significant implications for AD prediction and gene expression analysis:

- The dimensionality reduction techniques employed in this study have the potential to revolutionize AD prediction, making it more interpretable and precise.

highlights the superior performance of the WMBPSO-CNN-LSTM model in AD prediction using gene expression data. It achieved higher accuracy, AUC, F1 score, and recall compared to both the WMBPSO-CNN and WMBPSO-RNN models. The precision values were comparable between the WMBPSO-CNN-LSTM and WMBPSO-CNN models, indicating similar abilities to identify positive cases accurately. However, the WMBPSO-RNN model exhibited lower performance across all metrics, suggesting it may be less effective in capturing the complex relationships present in the gene expression data for AD prediction.

- The combination of WMBPSO and CNN-LSTM demonstrates the power of integrating feature selection with deep learning for complex biological data analysis.

- Future research should explore applications of these techniques in other disease prediction tasks and investigate novel approaches for feature selection and deep learning integration.

## V. LIMITATIONS AND FUTURE WORK

While our study has yielded promising results, it is essential to acknowledge its limitations and outline potential avenues for future research.

### A. Limitations

- Data Size: The study utilized a single gene expression dataset. Future work could explore the integration of multiple datasets to enhance the robustness and generalizability of the model.

- Generalization: Although our model exhibited exceptional performance on the specific dataset, further validation on diverse datasets and populations is necessary to establish its broader applicability.

- Feature Interpretation: While dimensionality reduction improved model performance, interpreting the biological significance of selected genes remains a challenge. Future research should focus on developing methods for gene function interpretation.

### B. Future Work

Several potential avenues of future research can be summed up as following: 1) Integrate biological constraints, such as gene pathway information or known gene-disease associations, to guide the gene selection process and ensure that the selected gene groups are biologically meaningful. 2) Group-based Velocity Update of the WMBPSO; modify the velocity update process to consider interactions between feature groups. The velocity update not only involves individual features but also considers the collective behavior of gene groups in the swarm. 3) Expanding the dataset by including additional samples from diverse populations and incorporating longitudinal data to enhance the generalizability and robustness of the WMBPSO-CNN-LSTM model. 4) Integration of Multi-Omics data such as DNA methylation, microRNA expression, or proteomics data, in combination with gene expression data, could provide a chance to validate the behavior of WMBPSO-CNN-LSSTM algorithm on such large-scale combined datasets. 5) Further validation of the WMBPSO-CNN-LSTM model on independent datasets to assess its performance and generalizability in real-world scenarios. 6) Advanced Deep Learning Architectures: Investigating state-of-the-art deep learning architectures and techniques, such as Transformers and attention mechanisms, may further enhance AD prediction accuracy.

## VI. CONCLUSION

In this study, we aimed to leverage the WMBPSO algorithm for dimensionality reduction in big gene expression

data. The accuracy score achieved by the WMBPSO algorithm in selecting genes was 0.98, indicating a significantly high level of accuracy. The objective was to develop an accurate AD prediction model using the WMBPSO algorithm in conjunction with a CNN-LSTM deep learning architecture. Through our investigations, we compared the performance of the WMBPSO-CNN-LSTM model with other deep learning and machine learning methods. Also, the performance of WMBPSO was compared with other common feature selection methods. The results obtained demonstrate the effectiveness of the WMBPSO algorithm for dimensionality reduction in big gene expression data. The WMBPSO-CNN-LSTM model achieved outstanding performance in AD prediction, as indicated by the high mean cross-validation accuracy (0.968), AUC (0.9958), F1 score (0.9677), recall (0.967), and precision (0.967). These metrics validate the potential of the WMBPSO algorithm for effectively selecting informative genes and improving the classification accuracy of the AD prediction model. Comparative analyses were conducted with other deep learning models, including WMBPSO-RNN and WMBPSO-CNN, as well as traditional feature selection methods such as ANOVA, lasso, and hybrid approach. The results indicated that the WMBPSO-CNN-LSTM model outperformed these approaches in terms of accuracy, AUC, F1 score, recall, and precision. In conclusion, our study has made significant strides in addressing the challenges of Alzheimer's Disease (AD) prediction using gene expression data. We have demonstrated that effective dimensionality reduction with the WMBPSO algorithm, coupled with the power of CNN-LSTM, can yield highly accurate predictions. Our research contributes by:

- Introducing an innovative approach to gene selection using WMBPSO, which outperforms traditional methods.

- Highlighting the potential of combining feature selection and deep learning for AD prediction.

- Offering valuable insights into the management of high-dimensional biological data.

While there are limitations to our study, such as dataset size and generalization, the future holds promising prospects for improving AD prediction, advancing gene function interpretation, and ultimately aiding in early diagnosis and intervention. Our work underscores the importance of interdisciplinary research at the intersection of bioinformatics and machine learning, paving the way for more precise and reliable disease prediction models in the era of precision medicine.

## REFERENCES

[1] X. Hou, J. Hou, and G. Huang, "Bi-dimensional principal gene feature selection from big gene expression data," *PLOS ONE*, vol. 17, 2022.

[2] J. Yang, Y. jie Li, Q. Liu, L. Li, A. Feng, T. Wang, S. Zheng, A. Xu, and J. Lyu, "Brief introduction of medical database and data mining technology in big data era," *Journal of Evidence-Based Medicine*, vol. 13, pp. 57 – 69, 2020.

[3] K. Wang, W. Wang, and M. Li, "A brief procedure for big data analysis of gene expression," *Animal Models and Experimental Medicine*, vol. 1, pp. 189 – 193, 2018.

[4] S. Zhao, C. K. Hong, C. Myers, D. Granas, M. A. White, J. C. Corbo, and B. A. Cohen, "A single-cell massively parallel reporter assay detects cell-type-specific gene regulation," *Nature Genetics*, vol. 55, pp. 346–354, 2023.

[5] H. Satam, K. Joshi, U. Mangrolia, S. Waghoo, G. Zaidi, S. Rawool, R. P. Thakare, S. Banday, A. K. Mishra, G. Das, and S. K. Malonia, "Next-generation sequencing technology: Current trends and advancements," *Biology*, vol. 12, 2023.

[6] Z. Sha, L. Zhu, Z. Jiang, Y. Chen, and T. Hu, "How complex is the microarray dataset? a novel data complexity metric for biological high-dimensional microarray data," *ArXiv*, 2023.

[7] H. Pan, S. X. Chen, and H. Xiong, "A high-dimensional feature selection method based on modified gray wolf optimization," *Appl. Soft Comput.*, vol. 135, 2023.

[8] M. Oliva, K. Demanelis, Y. Lu, M. Chernoff, F. Jasmine, H. Ahsan, M. G. Kibriya, L. S. Chen, and B. L. Pierce, "Dna methylation qtl mapping across diverse human tissues provides molecular links between genetic variation and complex traits," *Nature genetics*, vol. 55, no. 1, pp. 112–122, 2023.

[9] E. Lin, C.-H. Lin, and H.-Y. Lane, "Deep learning with neuroimaging and genomics in alzheimer's disease," *International Journal of Molecular Sciences*, vol. 22, 2021.

[10] P. Lavanya and E. Sasikala, "Deep learning techniques on text classification using natural language processing (nlp) in social healthcare network: A comprehensive survey," *2021 3rd International Conference on Signal Processing and Communication (ICPSC)*, pp. 603–609, 2021.

[11] W. Zhang, H. Li, Y. Li, H. long Liu, Y. min Chen, and X. chen Ding, "Application of deep learning algorithms in geotechnical engineering: a short critical review," *Artificial Intelligence Review*, vol. 54, pp. 5633 – 5673, 2021.

[12] S. Gao and D. Lima, "A review of the application of deep learning in the detection of alzheimer's disease," *International Journal of Cognitive Computing in Engineering*, vol. 3, pp. 1–8, 2022.

[13] T. Thaher, M. A. Awad, M. Aldasht, A. F. Sheta, H. Turabieh, and H. K. H. Chantar, "An enhanced evolutionary based feature selection approach using grey wolf optimizer for the classification of high-dimensional biological data," *J. Univers. Comput. Sci.*, vol. 28, 2022.

[14] F. Han, S. Zhu, Q. Ling, H. Han, H. Li, X. Guo, and J. Cao, "Gene-cwgan: a data enhancement method for gene expression profile based on improved cwgan-gp," *Neural Computing and Applications*, vol. 34, pp. 16 325 – 16 339, 2022.

[15] D. Wang, D. Tan, and L. Liu, "Particle swarm optimization algorithm: an overview," *Soft computing*, vol. 22, pp. 387–408, 2018.

[16] R. Poli, J. Kennedy, and T. M. Blackwell, "Particle swarm optimization," *Swarm Intelligence*, vol. 1, pp. 33–57, 1995.

[17] R. C. Eberhart, Y. Shi, and J. Kennedy, *Swarm Intelligence (Morgan Kaufmann series in evolutionary computation)*. Morgan Kaufmann Publishers, 2001.

[18] A. H. Alsaeedi, A. L. Albukhnefis, D. Al-Shammary, and M. Al-Asfoor, "Extended particle swarm optimization for feature selection of high-dimensional biomedical data," *Concurrency and Computation: Practice and Experience*, vol. 34, 2020.

[19] M. Martínez-Ballesteros, J. M. García-Heredia, I. A. Nepomuceno-Chamorro, and J. C. Riquelme-Santos, "Machine learning techniques to discover genes with potential prognosis role in alzheimer's disease using different biological sources," *Information Fusion*, vol. 36, pp. 114–129, 2017.

[20] C. Park, J. Ha, and S. Park, "Prediction of alzheimer's disease based on deep neural network by integrating gene expression and dna methylation dataset," *Expert Systems with Applications*, vol. 140, 2020.

[21] A. Sharma and P. Dey, "A machine learning approach to unmask novel gene signatures and prediction of alzheimer's disease within different brain regions," *Genomics*, vol. 113, no. 4, pp. 1778–1789, 2021.

[22] H. Chen, Y. He, J. Ji, and Y. Shi, "A machine learning method for identifying critical interactions between gene pairs in alzheimer's disease prediction," *Frontiers in Neurology*, vol. 10, 2019.

[23] H. Patel, R. Iniesta, D. Stahl, R. J. Dobson, and S. J. Newhouse, "Working towards a blood-derived gene expression biomarker specific for alzheimer's disease," *Journal of Alzheimer's Disease*, vol. 74, no. 2, pp. 545–561, 2020.

[24] B. Bogdanovic, T. Eftimov, and M. Simjanoska, "In-depth insights into alzheimer's disease by using explainable machine learning approach," *Scientific Reports*, vol. 12, no. 1, pp. 1–26, 2022.

[25] Z. Abbas, H. Tayara, and K. T. Chong, "Alzheimer's disease prediction based on continuous feature representation using multi-omics data integration," *Chemometrics and Intelligent Laboratory Systems*, vol. 223, 2022.

[26] N. Mahendran, P. M. D. R. Vincent, K. Srinivasan, and C.-Y. Chang, "Improving the classification of alzheimer's disease using hybrid gene selection pipeline and deep learning," *Frontiers in Genetics*, vol. 12, 2021.

[27] T. Lee and H. Lee, "Prediction of alzheimer's disease using blood gene expression data," *Scientific reports*, vol. 10, no. 1, 2020.

[28] M. S. Kamal, A. Northcote, L. Chowdhury, N. Dey, R. G. Crespo, and E. Herrera-Viedma, "Alzheimer's patient analysis using image and gene expression data and explainable-ai to present associated genes," *IEEE Transactions on Instrumentation and Measurement*, vol. 70, pp. 1–7, 2021.

[29] C. Maj, T. Azevedo, V. Giansanti, O. Borisov, G. M. Dimitri, S. Spasov, A. D. N. Initiative, P. Lió, and I. Merelli, "Integration of machine learning methods to dissect genetically imputed transcriptomic profiles in alzheimer's disease," *Frontiers in genetics*, vol. 10, 2019.

[30] S.-H. Kim, S. Yang, K.-H. Lim, E. Ko, H.-J. Jang, M. Kang, P.-G. Suh, and J.-Y. Joo, "Prediction of alzheimer's disease-specific phospholipase c gamma-1 snv by deep learning-based approach for high-throughput screening," *Proceedings of the National Academy of Sciences*, vol. 118, no. 3, 2021.

[31] J. Park, H. Kim, J. Kim, and M. Cheon, "A practical application of generative adversarial networks for rna-seq analysis to predict the molecular progress of alzheimer's disease," *PLoS computational biology*, vol. 16, no. 7, 2020.

[32] R. Xie, A. Quitadamo, J. Cheng, and X. Shi, "A predictive model of gene expression using a deep learning framework," *2016 IEEE International Conference on Bioinformatics and Biomedicine (BIBM)*, pp. 676–681, 2016.

[33] E. Alhenawi, R. Al-Sayyed, A. Hudaib, and S. Mirjalili, "Feature selection methods on gene expression microarray data for cancer classification: A systematic review," *Computers in Biology and Medicine*, vol. 140, 2022.

[34] N. An, L. Jin, H. Ding, J. Yang, and J. Yuan, "A deep belief network-based method to identify proteomic risk markers for alzheimer disease," *arXiv preprint arXiv:2003.05776*, 2020.

[35] Y. Lai, X. Lin, C. Lin, X. Lin, Z. Chen, and L. Zhang, "Identification of endoplasmic reticulum stress-associated genes and subtypes for prediction of alzheimer's disease based on interpretable machine learning," *Frontiers in Pharmacology*, vol. 13, 2022.

[36] Y. Kim and H. Lee, "Pinnet: a deep neural network with pathway prior knowledge for alzheimer's disease," *arXiv preprint arXiv:2211.15669*, 2022.

[37] A. El-Gawady, M. A. Makhlouf, B. S. Tawfik, and H. Nassar, "Machine learning framework for the prediction of alzheimer's disease using gene expression data based on efficient gene selection," *Symmetry*, vol. 14, no. 3, 2022.

[38] B. Jin, X. Cheng, G. Fei, S. Sang, and C. Zhong, "Identification of diagnostic biomarkers in alzheimer's disease by integrated bioinformatic analysis and machine learning strategies," *Frontiers in Aging Neuroscience*, 2023.

[39] N. Voyle, A. Keohane, S. Newhouse, K. Lunnon, C. Johnston, H. Soininen, I. Kloszewska, P. Mecocci, M. Tsolaki, B. Vellas *et al.*, "A pathway based classification method for analyzing gene expression for alzheimer's disease diagnosis," *Journal of Alzheimer's Disease*, vol. 49, no. 3, pp. 659–669, 2016.

[40] L. Wang and Z.-P. Liu, "Detecting diagnostic biomarkers of alzheimer's disease by integrating gene expression data in six brain regions," *Frontiers in genetics*, vol. 10, 2019.

[41] X. Li, H. Wang, J. Long, G. Pan, T. He, O. Anichtchik, R. Belshaw, D. Albani, P. Edison, E. K. Green *et al.*, "Systematic analysis and biomarker study for alzheimer's disease," *Scientific reports*, vol. 8, no. 1, 2018.

[42] Ncbi gene expression omnibus (geo). [Online]. Available: https://www.ncbi.nlm.nih.gov/geo/query/acc.cgi

[43] L. Ma and S. Tian, "A hybrid cnn-lstm model for aircraft 4d trajectory prediction," *IEEE access*, vol. 8, pp. 134 668–134 680, 2020.

[44] H. Nguyen and N. N. Chu, "An introduction to deep learning research for alzheimer's disease," *IEEE Consumer Electronics Magazine*, vol. 10, no. 3, pp. 72–75, 2020.

[45] L. Alzubaidi, J. Zhang, A. J. Humaidi, A. Al-Dujaili, Y. Duan, O. Al-Shamma, J. Santamaría, M. A. Fadhel, M. Al-Amidie, and L. Farhan, "Review of deep learning: Concepts, cnn architectures, challenges, applications, future directions," *Journal of big Data*, vol. 8, pp. 1–74, 2021.

[46] A. U. Rehman, A. K. Malik, B. Raza, and W. Ali, "A hybrid cnn-lstm model for improving accuracy of movie reviews sentiment analysis," *Multimedia Tools and Applications*, vol. 78, pp. 26 597–26 613, 2019.

# Development of YOLO-based Model for Fall Detection in IoT Smart Home Applications

Pengcheng Gao[*]

School of Cyber Security, Gansu University of Political Science and Law, Lanzhou 730070, Gansu, China

*Abstract*—In smart home applications, effective fall detection is a critical concern to minimize the occurrence of falls leading to injuries, especially for the assistance of elderly individuals. Various methods have been proposed, including both vision-based and non-vision-based approaches. Among these, vision-based approaches have garnered significant attention from researchers due to their practicality and applicability. However, existing vision-based methods face challenges such as low accuracy rates and high computational costs, which still need further exploration to enhance fall detection effectiveness. This study aims to develop a vision-based fall detection system tailored for smart home care applications. The objective of this study is to develop an accurate and lightweight fall detection method that is applicable in IoT platforms. A You Only Look Once (YOLO) based network is trained and tested to identify human falls accurately. The experimental results demonstrate that the developed YOLO-based technique shows promising outcomes for human fall detection and holds potential for integration in the Internet of Things (IoT) enabled smart home applications.

*Keywords—Smart home; IoT; elderly care; computer vision; deep learning; YOLO*

## I. INTRODUCTION

In recent years, the rapid progress in Information and Communication Technology (ICT) has brought about significant changes in people's lives thanks to groundbreaking innovations. This has led to the rise of intelligent environments, cities, and societies [1]. By leveraging cutting-edge technologies like Artificial Intelligence (AI) and the Internet of Things (IoT), we have the potential to greatly improve our quality of life. These advanced solutions empower us to monitor our surroundings and make well-informed decisions to achieve desired outcomes. Among these advancements, smart homes play a crucial role as the cornerstone of smart living. They are poised to be instrumental in the development of smart cities and societies since homes serve as the fundamental building blocks for both urban areas and social structures.

Presently, several socioeconomic factors are contributing to a significant decline in fertility rates and an increase in life expectancy [2]. As a result, a growing number of elderly individuals are striving to maintain their independence and stay in their own homes. To address this, an automated home-based solution that reduces the burden on healthcare services and provides valuable insights into fall risk becomes an appealing alternative [3]. Furthermore, with the global increase in the elderly population, healthcare considerations for seniors are becoming increasingly critical. For this reason, human motion

capture technologies are essential for elderly individuals living alone, as they can help tackle these challenges. By observing their posture, it becomes possible to monitor the health of elders, and if high-risk postures such as falling are detected, timely warnings can be sent [4], [5].

Compared to traditional Machine Learning (ML) algorithms, deep learning significantly simplifies the process of feature selection by automatically extracting abstract features through multiple hidden layers [6]. The effectiveness of deep learning in unsupervised learning and reinforcement learning has been proven, leading to a surge in the development of deep learning-based Human Activity Recognition (HAR) frameworks [5]. In particular, Convolutional Neural Networks (CNN), inspired by the hierarchical processing in the human visual cortex, have achieved remarkable success in image categorization in recent times [7]. CNN-based methods can automatically learn distinctive features from training data, making them highly efficient for feature extraction and classification tasks [8], [9].

Two general categories can be made for CNN-based identification tasks. The first category consists of two-stage detection algorithms that divide the phases of target detection into finding and identifying them. Conventional approaches, such as Region-Convolutional Neural Networks (R-CNN), have flaws and fall short of real-time performance requirements. Faster R-CNN and Faster R-CNN have been introduced, although they are still insufficient for real-time applications [10]. The second group uses a single-stage detection method that combines the positioning of the target with its identification.

This study addresses the research problem of devising a precise and resource-efficient fall detection method suitable for IoT platforms. The research questions include the design of such a method, the effectiveness of utilizing the YOLO5 network due to its memory-efficient and speedy detection characteristics, and the steps required for dataset curation to train and test the YOLO model in recognizing fallen postures for improved fall detection. The research objectives encompass creating an optimized fall detection solution for IoT environments, assessing the YOLO5 network's suitability for this purpose, and developing and preparing a dataset for robust fall posture recognition within the YOLO framework.

The main contributions of this study are as follows:

*1) Developing* a vision-based approach for fall detection with feasibility and applicability considerations.

*2) A* Yolo-based network implementation and model generation for human fall posture identification.

*3) Fall* dataset generation using image collection from various internet resources and annotation and augmentation process.

The rest of this paper is consisted as: Section II reviews the related works. Section III discuss about the research methodology. Section IV presents the results and discussion. Finally, this paper concludes in Section V.

## II. RELATED WORKS

Ajerla et al.'s [11] developed a fall detection framework based on an LSTM network that took advantage of edge computing tools like laptops, reducing the requirement to upload raw data to the cloud for real-time fall event prediction. The system used the open-source Apache Flink streaming engine to process the three-axis accelerometer raw data. A part of the MobiAct dataset, which is openly accessible, was used for training and testing. To get the best results, the system advised putting sensors at the waist—the suggested framework successfully anticipated fall occurrences using real-time fall data with an amazing accuracy of 95.8%. The use of various sensors and data streams led to improved performance.

Queralta et al. [12] proposed a fall detection system for health monitoring facilities using low-power wide-area network (LPWAN) technologies with Edge computing and Fog computing, as well as a compression technique for data transfer, lowering system latency. To recognize falls from the received data, LSTM and RNN networks were developed on the edge computer. These edge gateways were used to transmit real-time alerts and notifications while unprocessed data was transferred to the cloud for online processing. With this strategy, the operation was possible even in places with poor network access and increased battery life.

By suggesting an approach based on video analysis, Wang et al. [13] attempted to increase fall detection accuracy and speed in complex contexts. The introduction of the YOLOv3 network model as the detection algorithm was the main contribution. In order to train and test the network model on a GPU server, they constructed their dataset for human fall detection using the Pascal VOC data set format. According to experimental data, the method is more reliable and efficient than traditional fall detection algorithms, achieving a mAP of 0.83 and an AP down at 0.97.

In study [14], an approach to detecting human falls based on the Fast Pose Estimation technique was presented. The method classified data from picture frames using TD-CNN-LSTM and 1D-CNN models, demonstrating excellent accuracy. The suggested technique proved to be a valuable addition to reliable human fall detection, suitable for implementation in edge devices due to its minimal computational and memory requirements. They enhanced the URFD dataset for training by applying rotation, brightness adjustments, horizontal flipping, and gamma correction.

## III. RESEARCH METHODOLOGY

This section presents the research methodology. Firstly, the background of the YOLO method is discussed. Secondly, the preparation of the dataset is presented. Thirdly, the implementation environment using Google Colab is explained, and lastly, the training and testing procedure is presented for fall detection.

### A. Background of YOLO

YOLO (You Only Look Once) was a pretrained object detector designed to recognize common objects like tables, chairs, cars, phones, and more [15]. A newer version of the YOLO algorithm, called YOLOv5, has been proposed with enhancements over YOLOv3. YOLOv5 achieves greater precision and smaller model size, leading to significantly faster detection speed compared to its predecessor. Despite its potential, the YOLOv5 technique has not yet been widely applied in fall detection [16]. Therefore, this paper aims to improve the YOLOv5 model for detecting senior fall behavior.

The YOLOv5 is one of the most prominent models in the one-stage detection series, avoiding the recomputation of candidate areas utilized in the two-stage series. It boasts excellent recognition accuracy and quick inference. The YOLOv5 architecture comprises four primary model structures: YOLOv5l, YOLOv5x, YOLOv5m, and YOLOv5s, each offering progressively fewer complex networks. Additionally, a YOLOv5n model was later developed with only 1.9 MB parameters, the same depth as YOLOv5s but with half the network width, making it suitable for deployment on mobile devices.

As depicted in Fig. 1 [16], the YOLOv5 baseline architecture consists of three main components: the backbone, neck, and head. Fig. 1(a) to Fig. 1(d) illustrates the composition of modules related to the baseline architecture. One of the Backbone structures is a Convolutional Neural Network (CNN), which combines various fine-grained images to form image features.

The architecture utilizes the conv module for 2D convolution, regularization, and activation. The c3 module aids in feature extraction, reducing the model size and enhancing inference speed. The up-sample and concat modules handle feature map sampling and combination. The spatial pyramid pooling (SPP) module expands the network's perceptual area. The Neck structure improves information flow with feature pyramid network (FPN) and path aggregation networks (PAN). Adaptive pooling connects features for optimal data utilization. Overall, these components optimize the model's accuracy and efficiency.

### B. Dataset Preparation

The dataset for fall detection was compiled from diverse sources, including Google Images, to create a custom dataset. This dataset consists of images categorized into three labels: "Fall Detected," "Walking," and "Sitting ". The initial dataset involves 485 images. To prepare the dataset with mode diversity, image augmentation is performed. After augmentation, total dataset involves 1455 images. The labels directory also has two subdirectories, namely "train", "val." and "test". Within these directories, text files are provided,

containing labels corresponding to specific images. Fig. 2 displays some examples from our dataset.

The dataset for fall detection may not be large by industry standards, but it's essential to consider its specific context and the chosen model's complexity. As our experimental results indicated, it is sufficient for a well-designed model. Additionally, the dataset is diverse and representative of real-world scenarios, that it helps the model generalize effectively.
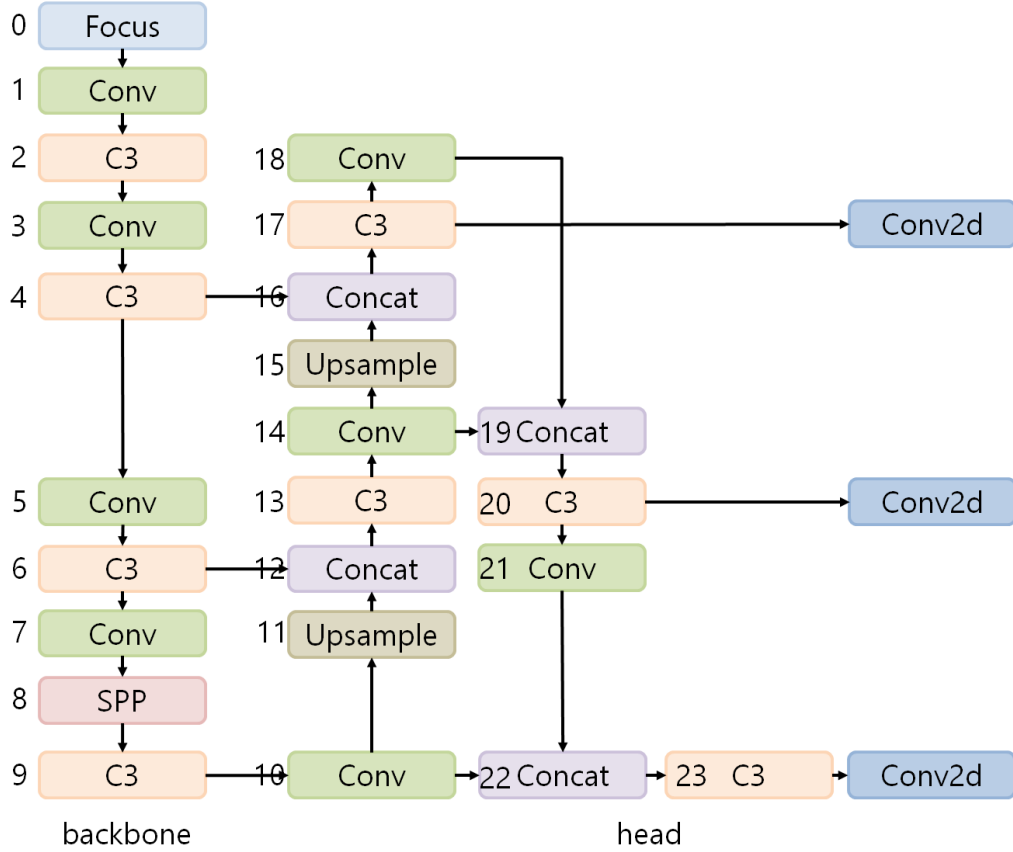


Fig. 1. The architecture of the YOLOv5 network.



Fig. 2. Sample images from the dataset.

## C. Training and Testing

When training an object detector, one common approach is to start with a preexisting model that has already been trained on large and diverse datasets. These pretrained models have learned to recognize various objects from the data they were initially trained on. Although the pretrained weights may not include specific objects relevant to the current experiment, they still capture valuable general features and patterns that can be beneficial for the new task.

This process of using a pretrained model as a starting point and fine-tuning its weights for a specific task is called transfer learning. By leveraging transfer learning, we can save time and computational resources, as the pretrained model has already learned to detect common objects effectively. The model acts as a feature extractor that can be fine-tuned to recognize the specific objects we need in our experiment.

In this case, a pretrained model containing weights trained on the COCO dataset is used as the starting point for the object detection task. COCO is a large and diverse dataset that includes a wide range of objects from various categories. Using a model pretrained on COCO, our network can benefit from the learned features, leading to faster convergence during training.

With transfer learning, we can achieve good results with fewer training data. In this experiment, the total dataset consists of 1455 images. To split the dataset for training, validation and testing, 70% of the images are used for training the model, and the remaining 20% are used for validating, and 10 % for testing for performance evaluation of the model.

In summary, transfer learning is a powerful technique that allows us to leverage existing knowledge from pretrained models to boost the performance of our object detection task. Utilizing a pretrained model and carefully selecting the appropriate amount of data for training and validation, we can efficiently train an accurate and effective object detector for our specific needs.

## IV. RESULTS AND ANALYSIS

In this section, we discuss the experiment's details, then show the training results using pretraining weights and compare the three models of YOLOv5.

### A. Experimental Results

At this stage, we show a series of the model's stress measurement results and achieved high accuracy. Fig. 3 illustrates the results of the prediction fall in the dataset.
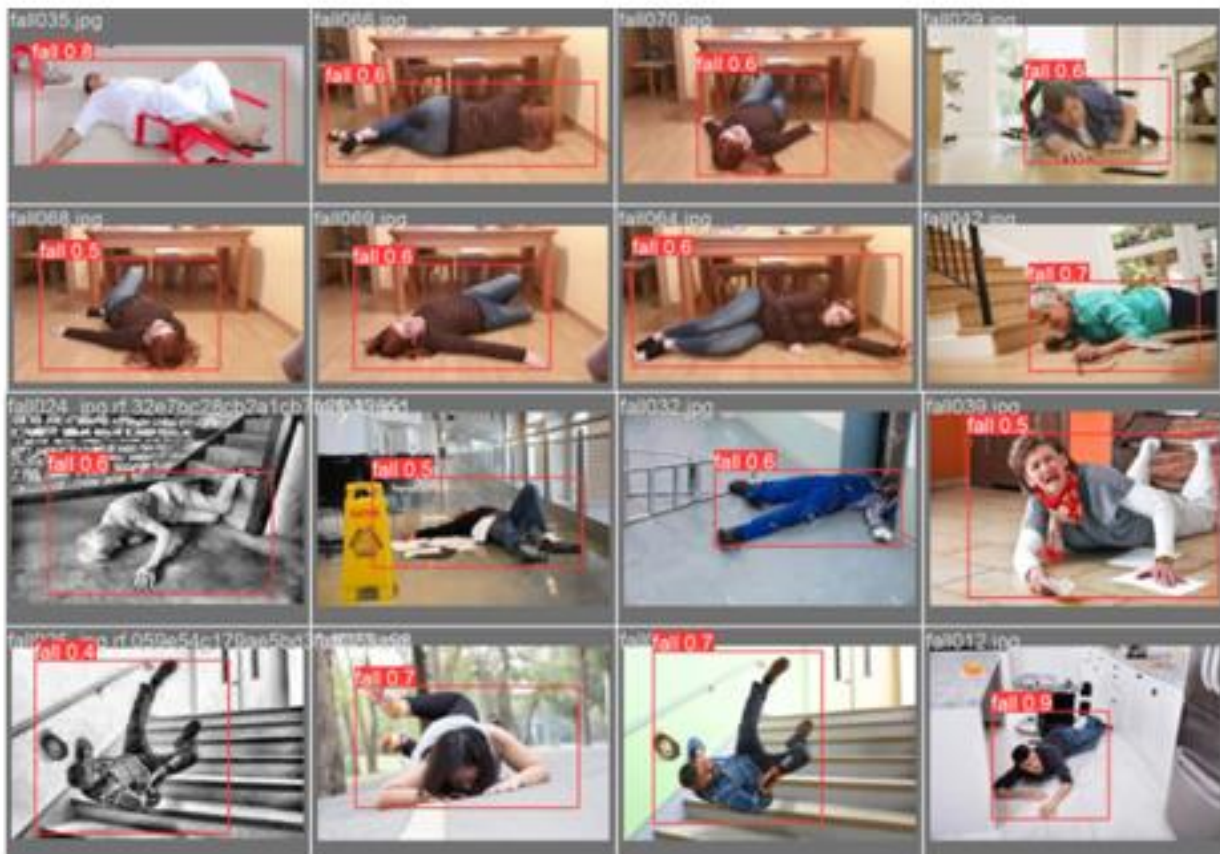


Fig. 3. Prediction results of fall detection.

### B. Model Evaluation

The first version of our model was trained for the training set. The results of it are shown in Fig. 4. Label 0 is for falling, label 1 for walking and label 2 for sitting. As experimental results are shown in Fig. 4, this model achieved relatively accurate results.
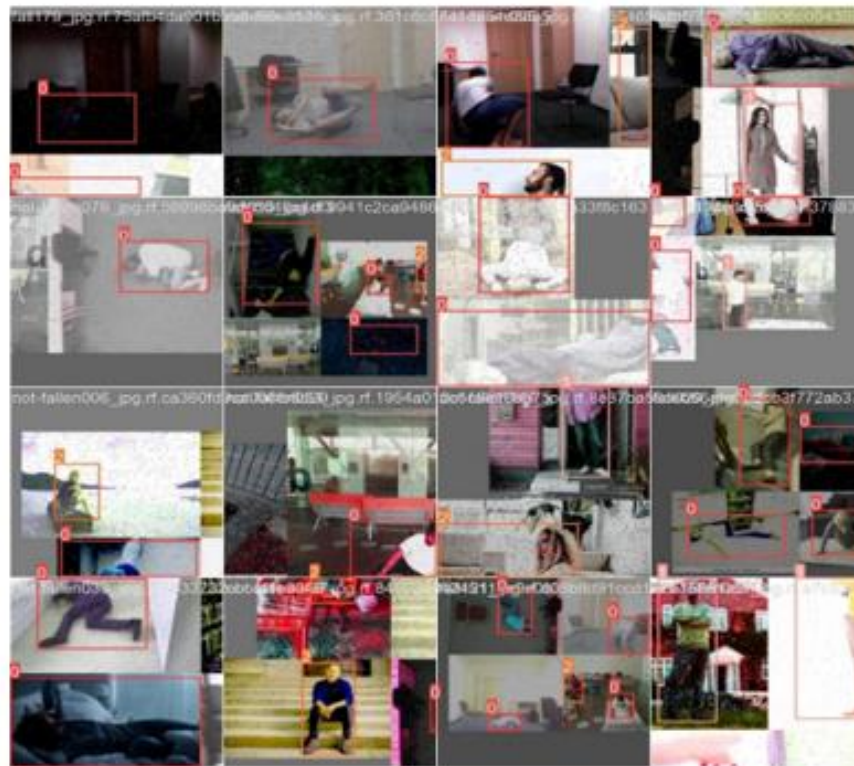
Fig. 4. Labels in the training process.

Various performance metrics are computed to evaluate the fall detection model. These metrics typically include precision, recall, and F1 score. We calculated the precision rate and recall rate. The results of the evaluation metrics of the trained model are shown in Fig. 5. Precision measures the accuracy of fall predictions, recall measures the model's ability to detect all falls, and the F1 score combines precision and recall into a single value. An analysis of the model's errors is performed to gain insights into its performance. This involves examining false positive and false negative predictions [18]. False positives are instances where the model incorrectly identifies a non-fall instance as a fall, while false negatives are cases where the model fails to detect an actual fall. Analyzing these errors helps identify areas for improvement in the model and dataset. Fig. 5 to Fig. 7 illustrates the performance metrics.
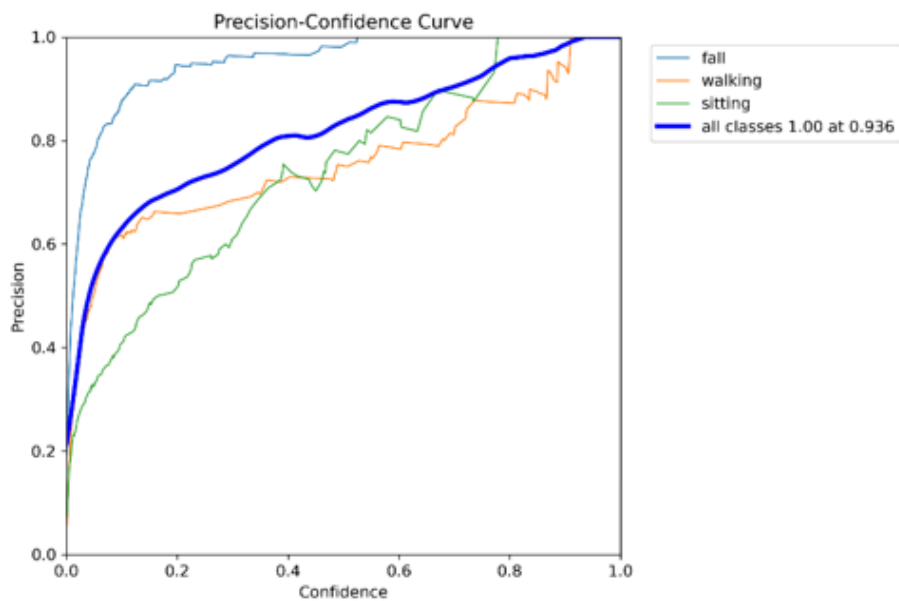


Fig. 5. Result of precision metric.

As shown in Fig. 5, a precision curve graph for a generated YOLOv5 model fall detection system with fall, walking, and sitting classes shows the relationship between the confidence rate and the precision rate. The X-axis represents the confidence rate, which indicates the level of confidence the model has in its predictions. In contrast, the Y-axis represents the precision rate, which measures the accuracy of the fall detection system. To obtain accurate results based on the obtained precision confidence from the generated YOLOv5 model, the following steps are typically followed:

Prediction and Confidence Threshold: The YOLOv5 model is applied to the test dataset, and for each detected object, the model assigns a confidence score or probability indicating its confidence in the prediction. The confidence score represents the model's belief that the object belongs to a particular class, such as falling, walking, or sitting. To generate the precision curve graph, different confidence thresholds are set to analyze the trade-off between precision and recall.

Precision Calculation: For each confidence threshold, the model's predictions are compared against the ground truth labels. True positive (TP) refers to the correct detection of a fall instance, false positive (FP) represents a non-fall instance being incorrectly identified as a fall, and false negative (FN) indicates a missed detection of a fall. The precision is then calculated using the formula: Precision = TP / (TP + FP) [17,18]. By examining the precision curve graph, one can identify the confidence threshold that provides the desired precision rate for fall detection. It allows for fine-tuning the system based on the specific requirements, striking a balance between accurate fall detection and minimizing false positives.

As depicted in Figure 5, the achieved precision rate of 0.93 for the YOLOv5 model in detecting fall, walking, and sitting classes is highly indicative of its effectiveness. A precision rate of 0.93 implies that 93% of the predicted positive cases were indeed true positives, minimizing false positives. This high precision indicates the model's ability to accurately classify these activities, reducing the likelihood of misclassification.
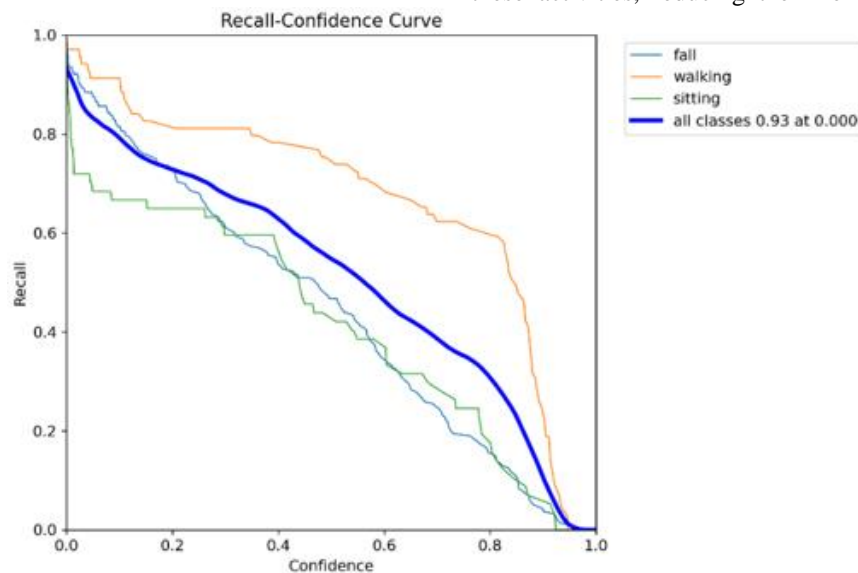


Fig. 6. Result of recall metric.

Fig. 6 illustrates the recall curve. A recall curve graph for a generated YOLOv5 model fall detection system with fall, walking, and sitting classes shows the relationship between the confidence rate and the recall rate. The X-axis represents the confidence rate, which indicates the level of confidence the model has in its predictions, while the Y-axis represents the recall rate, which measures the ability of the fall detection system to correctly identify all instances of falls.

For recall calculation, the model's predictions are compared against the ground truth labels for each confidence threshold. True positive (TP) refers to the correct detection of a fall instance, false positive (FP) represents a non-fall instance being incorrectly identified as a fall, and false negative (FN) indicates a missed detection of a fall. The recall is then calculated using the formula: Recall = TP / (TP + FN) [19,20].

Moreover, for recall curve plotting, as the confidence threshold is varied, the recall rate is calculated at each point. These recall values are plotted against the corresponding confidence thresholds on the graph. The resulting recall curve shows how the recall rate changes as the confidence rate increases. A higher recall rate indicates that the fall detection system is more effective in correctly identifying all fall instances. The recall curve graph allows us to analyze the relationship between recall and confidence thresholds. Based on the desired trade-off between recall and precision, an optimal confidence threshold can be selected. If maximizing the number of detected falls is the priority, a lower confidence threshold can be chosen, which may result in higher recall but potentially more false positive predictions. By examining the recall curve graph, one can identify the confidence threshold that provides the desired recall rate for fall detection.

As depicted in Fig. 6, the overall recall rate is 0.93 for the YOLOv5 model in detecting fall, walking, and sitting classes. I show that the model successfully captured 93% of all actual positive cases, demonstrating its ability to detect these classes with a high level of sensitivity.
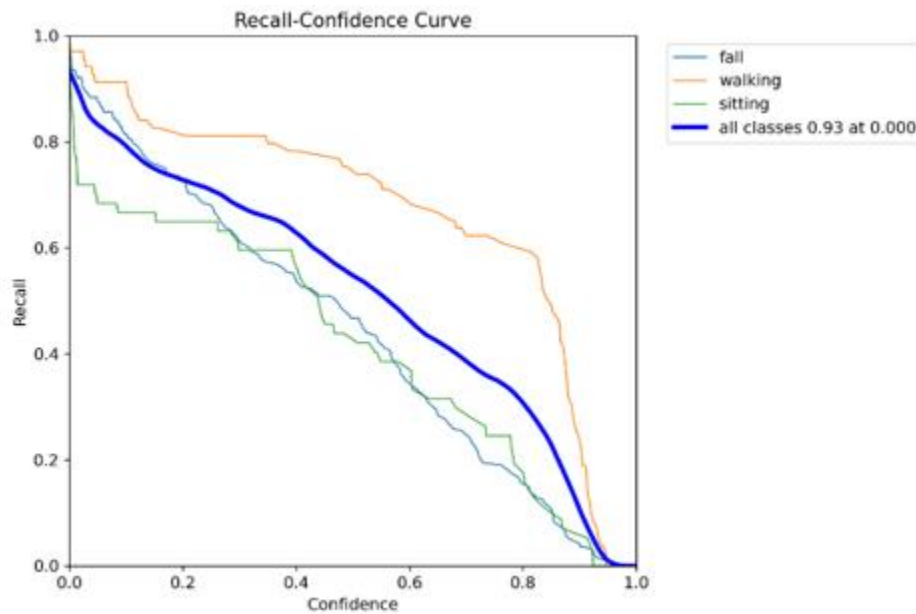
Fig. 7.   Result of precision-recall curve.

As shown in Fig. 7, the precision-recall curve graph for a generated YOLOv5 model fall detection system with fall, walking, and sitting classes shows the relationship between the confidence rate and the precision-recall rate. The graph provides a visual representation of how precision and recall change as the confidence threshold varies. Precision measures the accuracy of fall predictions, while recall measures the ability to detect all fall instances. By examining the curve, the optimal confidence threshold can be determined based on the desired balance between precision and recall.

The precision-recall curve graph helps in evaluating the performance of the fall detection system and selecting the appropriate confidence threshold. A higher precision indicates more accurate fall predictions, while a higher recall indicates a greater ability to detect all fall instances. The graph allows for the analysis of the trade-off between precision and recall, enabling the system to be fine-tuned to meet specific requirements. By selecting the optimal confidence threshold based on the precision-recall curve, the generated YOLOv5 model can achieve accurate results in detecting falls while minimizing false positives and false negatives.

Finally, as illustrated in Fig. 7, the overall precision-recall rate of 0.93 for the YOLOv5 model in detecting fall, walking, and sitting classes. This metric signifies a balanced performance in terms of precision (the ability to correctly classify positive cases) and recall (the ability to capture all actual positive cases). This obtained score demonstrates the model strikes a favorable balance between minimizing false positives and successfully identifying true positives.

## V.   CONCLUSION

In IoT smart home applications, detecting human fall detection is a difficult problem. The high complexity, poor accuracy, and time constraints of human fall detection in smart home applications is the focus of this work. The aim of this study is to develop an accurate and lightweight fall detection method that is applicable in IoT platforms. It developed a vision-based fall detection system that can recognize human fallen posture for use in smart home applications. The developed method involves training and testing a YOLO network to identify the postures in the prepared dataset. Based on the YOLO5 algorithm, which offers a high accuracy rate and satisfactory speed in posture identification, this Yolo-based technique was developed. One limitation of this study is the reliance on a relatively small dataset, which may limit the diversity and representation of fall-related scenarios. A larger and more diverse dataset could provide a more comprehensive understanding of fall detection in various real-world situations, potentially enhancing the model's generalizability and robustness to different environmental and contextual factors. Future work in this area could involve the expansion of the dataset to include a wider variety of fall-related scenarios, encompassing different environments, age groups, and diverse physical conditions. This would help improve the model's ability to handle a more extensive range of fall detection challenges. Other potential directions for future study include improving the accuracy and performance of the system by exploring alternative deep learning models or refining the existing technique. Another direction is to focus on the real-time implementation and deployment of the system in real-world smart home environments, considering factors such as scalability, reliability, and integration with IoT technologies. These advancements would contribute to the effective utilization of the system in IoT-based smart home applications.

## REFERENCES

[1]   E. Alqahtani, N. Janbi, S. Sharaf, and R. Mehmood, "Smart homes and families to enable sustainable societies: A data-driven approach for multi-perspective parameter discovery using bert modelling," Sustainability, vol. 14, no. 20, p. 13534, 2022.

[2]   S. Zolfaghari, E. Khodabandehloo, and D. Riboni, "TraMiner: Vision-based analysis of locomotion traces for cognitive assessment in smart-homes," Cognit Comput, vol. 14, no. 5, pp. 1549–1570, 2022.

[3] G. Forbes, S. Massie, and S. Craw, "Fall prediction using behavioural modelling from sensor data in smart homes," Artif Intell Rev, vol. 53, no. 2, pp. 1071–1091, 2020.

[4] W. Quan, J. Woo, Y. Toda, and N. Kubota, "Human posture recognition for estimation of human body condition," Journal of Advanced Computational Intelligence and Intelligent Informatics, vol. 23, no. 3, pp. 519–527, 2019.

[5] L. M. Dang, K. Min, H. Wang, M. J. Piran, C. H. Lee, and H. Moon, "Sensor-based and vision-based human activity recognition: A comprehensive survey," Pattern Recognit, vol. 108, p. 107561, 2020.

[6] T. Plötz and Y. Guan, "Deep learning for human activity recognition in mobile computing," Computer (Long Beach Calif), vol. 51, no. 5, pp. 50–59, 2018.

[7] S. Ramasamy Ramamurthy and N. Roy, "Recent trends in machine learning for human activity recognition—A survey," Wiley Interdiscip Rev Data Min Knowl Discov, vol. 8, no. 4, p. e1254, 2018.

[8] A. Kamel, B. Sheng, P. Yang, P. Li, R. Shen, and D. D. Feng, "Deep convolutional neural networks for human action recognition using depth maps and postures," IEEE Trans Syst Man Cybern Syst, vol. 49, no. 9, pp. 1806–1819, 2018.

[9] A. Khan, A. Sohail, U. Zahoora, and A. S. Qureshi, "A survey of the recent architectures of deep convolutional neural networks," Artif Intell Rev, vol. 53, pp. 5455–5516, 2020.

[10] T. Chen, Z. Ding, and B. Li, "Elderly Fall Detection Based on Improved YOLOv5s Network," IEEE Access, vol. 10, pp. 91273–91282, 2022.

[11] D. Ajerla, S. Mahfuz, and F. Zulkernine, "A real-time patient monitoring framework for fall detection," Wirel Commun Mob Comput, vol. 2019, pp. 1–13, 2019.

[12] J. P. Queralta, T. N. Gia, H. Tenhunen, and T. Westerlund, "Edge-AI in LoRa-based health monitoring: Fall detection system with fog computing and LSTM recurrent neural networks," in 2019 42nd international conference on telecommunications and signal processing (TSP), IEEE, 2019, pp. 601–604.

[13] X. Wang and K. Jia, "Human fall detection algorithm based on YOLOv3," in 2020 IEEE 5th International Conference on Image, Vision and Computing (ICIVC), IEEE, 2020, pp. 50–54.

[14] M. Salimi, J. J. M. Machado, and J. M. R. S. Tavares, "Using deep neural networks for human fall detection based on pose estimation," Sensors, vol. 22, no. 12, p. 4544, 2022.

[15] M. Hatab, H. Malekmohamadi, and A. Amira, "Surface defect detection using YOLO network," in Intelligent Systems and Applications: Proceedings of the 2020 Intelligent Systems Conference (IntelliSys) Volume 1, Springer, 2021, pp. 505–515.

[16] G. Dai, L. Hu, and J. Fan, "DA-ActNN-YOLOV5: hybrid YOLO v5 model with data augmentation and activation of compression mechanism for potato disease identification," Comput Intell Neurosci, vol. 2022, 2022.

[17] Aghamohammadi, A., Ang, M.C., A. Sundararajan, E., Weng, N.K., Mogharrebi, M. and Banihashem, S.Y. A parallel spatiotemporal saliency and discriminative online learning method for visual target tracking in aerial videos. Plos one, 13(2), p.e0192246, 2018.

[18] Lin, Bor-Shing, Tiku Yu, Chih-Wei Peng, Chueh-Ho Lin, Hung-Kai Hsu, I-Jung Lee, and Zhao Zhang. "Fall detection system with artificial intelligence-based edge computing." IEEE Access 10 (2022): 4328-4339.

[19] Gomes, Mouglas Eugenio Nasario, David Macedo, Cleber Zanchettin, Paulo Salgado Gomes de-Mattos-Neto, and Adriano Oliveira. "Multi-human fall detection and localization in videos." Computer Vision and Image Understanding 220, 2022.

[20] Yacchirema, Diana, Jara Suárez de Puga, Carlos Palau, and Manuel Esteve. "Fall detection system for elderly people using IoT and ensemble machine learning algorithm." Personal and Ubiquitous Computing ,2019, pp. 801-817.

# Identification of the False Data Injection Cyberattacks on the Internet of Things by using Deep Learning

Henghe Zheng[1], Xiaojing Chen[2*], Xin Liu[3]

Internet Security and Information Management Center, Jining University, Qufu 273155, Shandong, China[1]
Library, Zhejiang Gongshang University, Hangzhou 310018, Zhejiang, China[2]
Information Technology Center, JiNing Medical University, Jining 272067, Shandong, China[3]

*Abstract*—With the expanding utilization of cyber-physical structures and communication networks, cyberattacks have become a serious threat in various networks, including the Internet of Things (IoT) sensors. The state estimation algorithms play an important role in defining the present operational scenario of the IoT sensors. The attack of the false data injection (FDI) is the earnest menace for these estimation strategies (adopted by the operators of the IoT sensor) with the injection of the wicked data into the earned mensuration. The real-time recognition of this group of attacks increases the network resilience while it ensures secure network operation. This paper presents a new method for real-time FDI attack detection that uses a state prediction method basis on deep learning along with a new officiousness identification approach with the use of the matrix of the error covariance. The architecture of the presented method, along with its optimal group of meta-parameters, shows a real-time, scalable, effective state prediction method along with a minimal error border. The earned results display that the proposed method performs better than some recent literature about the prediction of the remaining useful life (RUL) with the use of the C-MAPSS dataset. In the following, two types of attacks of the false data injection are modeled, and then, their effectiveness is evaluated by using the proposed method. The earned results show that the attacks of the FDI, even on the low number of the sensors of the IoT, can severely disrupt the prediction of the RUL in all instances. In addition, our proposed model outperforms the FDI attack in terms of accuracy and flexibility.

*Keywords—Cyberattacks; false data injection (FDI) attacks; internet of things (IoT); deep learning*

## I. INTRODUCTION

The current developments and the rapid growth of the Internet of Things sensors have increased the possibility of predictive maintenance. This capability is a method for the prevention of asset damage by the generation of data analysis and the template identification for the prediction of the subjects before which they occur. Using these PdM techniques leads to an $20\% - 25\%$ increment in productivity, a 35%−45% decrease in downtime and the 25%−20% decrease in maintenance cost [1]. Due to this good feature, the equipped PdM solutions with machine learning and IoT sensors are transforming the transportation, oil, gas, aerospace, automotive, national defense and construction industries. For example, recently, the algorithms of deep learning have displayed massive achievement in these applications [2]. However, unfortunately, the sensors of the IoT and the algorithms of deep learning widely are delicate to cyberattacks

[3]. This bad feature is a considerable menace to the overall system of the PdM. Due to the provided reportage by Malwarebytes, the cyber menace versus the factories/occupations has enhanced to over 200% in the prior year [4].

In particular, recognizing covert attacks like the false data injection (FDI) attack [5] in the PdM system is quite challenging due to the unique nature of this attack type. The attack of the false data injection (FDI) [5] is in such a way that an attacker secretly compromises the measurements of the sensors of IoT. This is done by the method that the measurements of the manipulated sensor bypass the original detection method of the "defective data" by the sensors. Then they propagate into the output of the sensor. The attack of FDI can be fulfilled by completing the communication network of the sensors, the physical sensors and the processing applications of the data. These types of attacks in the system of PdM may not even display their effect. But, in lieu, the attack propagates aboard the sensor to the machine learning part of the system of PdM. Next, it tricks the system with the prediction of the possession defeat and or the interval of the delayed maintenance. It may evince a considerable cost with the creation of an unplanned defeat and or human life loss on the applications of the safety-critical [6], [7], [8]. In the past, the attacks of the FDI have made the very incidents of the known catastrophic. The most important example is the Northeast blackout in the United States in 2003 and the attack on the Ukrainian power grid. These attacks have influenced more than 230,000 people. They have been without power for multiple hours. A vast investigation has been done about the identification and reduction of the attacks of FDI in the field of cyber-physical systems [9], [10], [11]. The current users of this type of system for aircraft engine maintenance are Honeywell, Rolls-Royce, Pratt & Whitney, US Air Force and General Electronics [6], [12], [13].

The proposed solutions for sensor attack detection, which are provided so far in the field of the system of cyber-physical and IoT, are not enough for the solution of this subject because utmost of the existing method travail from the scalability subjects and the resource overhead when they deployed individually on thousands of the sensors. Many IoT sensors have limited power and limited resources. This paper presents a real-time attendance recognition method for these attacks in earned mensuration by applying the models of deep learning for the precise state prediction along with an impressive abnormal identification approach in the predicted

states with the use of the matrix of the error covariance. When the change rate of the eigenvalues of the error covariance matrix exceeds a predefined threshold, then the network operator indicates the presence of the attack of FDI on a collection of the accessible mensuration. This shows an effective deployment of the scalable 920D. Therefore, our article contributions are as the below:

- By effectively adjusting the presented deep learning-based method parameters, a collection of the indices of the minimum error have been obtained. An encyclopedic compersion between two non-uniform deep learning-based methods and a conventional ML-based method, such as the SVM and an actuarial prediction method, such as the integrated moving average of the autoregressive, is carried out in this work.

- By incorporating the noise into the existing mensuration, the presented deep learning-based method provides flexible action with minimal changes on the indices of the error.

- The presented abnormal recognition scheme shows a robust, real-time and excellent FDI attack recognition approach with the tracking of the change rate of the eigenvalues of the matrix of the error covariance.

- Since our presented method does not require the major modification of the standard BDD, therefore, it represents a cost-impressive method.

The continuation of this paper is as the below: In Section II, the related works is presented. In Section III of the paper, the proposed algorithm details are presented. Then, Section IV presents the earned results from the designed experiments. Eventually, Section V presents the potential conclusions and future perspectives.

## II. RELATED WORKS

The available studies on the data injection attacks on smart networks are listed in [27] to [35]. The work in [29] introduces an analysis of the economic effects of data injection on electricity markets in the smart power grid. In this reference, it is assumed that an attacker participates in the virtual transactions of the electricity market with complete information that he has from the network and it designs his attack strategy based on the manipulation of the electricity price in order to maximize the profitability and by observing all the limitations of the attack. In [30], the operation of the data injection attack in the electricity market environment is considered for a connected micro-grid to the power system. This attack can affect the optimal outputs of micro-grid energy management, such as the total cost of production. The research in [31] suggests the monetization of malicious data attack on electric energy production markets and the necessary strategy to maximize the revenue. The study in [32] proposes LR as a type of FDIA that the load distribution attack can affect the operation of the smart grid by attacking the economic load distribution bound by the security constraints (SCED). To solve this problem, [33] has introduced the problem of the distributed resilient economic load distribution

under cyber-attacks. With the aim of directly controlling local marginal prices (LMPs) in real time through FDIA, [34], a control theory based on a method is presented to analyze the effect of attack implements pricing stability.

In [35] and [36], a zero-sum game is formulated between an attacker and a defender, in which the attacker changes the estimated throughput of the lines to manipulate the prices. According to this game theory, a two-level optimization problem is formed. In [37] and [38], the economic effect of the structured information attacks as a generalized type of FDIA in electricity markets by using the virtual bidding activities is studied. The structured information of smart grids is used to exploit the system for management. The network is very vital in a safe way, but this information can be manipulated by a cyber-attacker by changing the on/off state of the power switches. In addition to these, recently in [39], an attack strategy has been proposed in which a cyber-attacker can effectively change LMPs by manipulating some vital parameters of the model and achieve the financial gain. Also, an FDIA can be well matched with a coordinated physical attack and actually create a coordinated physical-cyber-attack (CCPA), which has a more destructive effect on the normal operation of the smart network.

In [40], the coordinated attack includes connecting the physical shortening of the transmission lines, after infiltrating the communication network with the cyber protection layers. The research in [41] has designed a CCPA with the aim of maximizing disruption in the day-ahead (DA) and real-time electricity markets. The study in [42], an attack of a CCPA based on AC state estimation proposes to disrupt the operation of the electricity market by manipulating the nodal prices. All the above related studies are based on the hypothesis that the cyber attacker has complete knowledge about the target smart grid information, which includes the network topology, the branch parameters, etc. In fact, in any given smart grid, the network information is vast and highly secure and vital. Moreover, information is dynamic; because the network topology can be reconfigured in both normal and event situations. Therefore, in practice, it is very difficult for a limited attacker to access the complete information of the network. In several recent works based on [33] to [35], this aggressive challenge in FDIA design has been addressed to some extent according to different tools, techniques and requirements.

In study [43], the attacker has formulated a secret profitable attack without prior knowledge of network topology and only through phasor observations by using the linear independent component analysis. In study [44], the attacker designs an online attack strategy against the real-time electricity market based only on real-time information received from measuring devices and without the need for the network topology information. A profitable data injection attack on electricity markets by limited attackers with incomplete network information is studied in [45]. In this reference, the uncertainties associated with random network information, a model and a possible framework for designing an undetectable and profitable attack are presented. One of the problems in this reference is the need for past data to properly

estimate the probability distribution functions of the parameters.

## III. PROPOSED SCHEME FOR THE FDI ATTACK DETECTION

In this section, the presented method for detecting the attacks of false data injection is detailed. For this purpose, first, a brief explanation of these types of attacks and how the definition of them are provided. In the following, the proposed scheme is expressed.

### A. Definition of FDI Attack

At first, it should be stated that the only purpose of the attack of the FDI is the bypassing of the remaining test in the centers of control with the attenuation of the climacteric vulnerabilities of the sensors and RTUs. This progressive cyberattack scheme in various networks (such as the Internet of Things) leads to the change of a group of the state estimations from a group of the obtained mensuration. A vector expansion approach of the indiscoverable covert attack for the nonlinear algorithm of the state prediction is presented, which shows:

$$a_1 = h(\hat{x}_{a_1}) - h(\hat{x}) \tag{1}$$

$$\hat{x}_{a_1} = \hat{x} + c' \tag{2}$$

$$z_{a_1} = z + a_1 \tag{3}$$

where, $a_1 \in R^m$ represents the vector of the injected attack to the obtained collection of the mensuration $z$ for the presentation of a group of the corrupt mensuration $z_{a_1} \in R^m$. Therefore, it creates a set of the false estimation states $\hat{x}_{a_1} \in R^n$. The statistical remaining test, which is performed by the BDD in the above conditions, can be seen as follows:

$$r_{a_1} = ||z_{a_1} - h(\hat{x}_{a_1})||_2 = ||z + a_1 - h(\hat{x}_{a_1}) + h(\hat{x}) - h(\hat{x})||_2 = ||z - h(\hat{x})||_2 = r \tag{4}$$

From the above equations, it can be seen which vector of the extended attack can bypass as successfully the remaining test. Therefore, it leads to climacteric operational scenarios.

The existing operators in the center of the control adopt the algorithms of the state prediction for the definition of the climacteric network actions, such as the load prediction, the load distribution of the economy, and so on [14]. The mensuration in the SCADA is broadcasted via BDDs to meet the integrity and the quality of the mensuration. Then the bad information removes according to the noise in the networks of communication, the meter malfunction, and so on. In most of the unfavorable papers [15], [16], [17], a method of the nonlinear state prediction is presented, that is shown as follows:

$$z = h(x) + e_1 \tag{5}$$

where, $z \in R^m$ represents the available measurements which are obtained from the BDDs. Also, $x \in R^n$ represents the set of operational states while $e_1 \in R^m$ displays the vector of the error for the prediction method. Furthermore, $h()$ represents the nonlinear function that draws a collection of the obtained mensuration by the network operational states. For the estimation of a collection of the operational states with the use of the method of the nonlinear state prediction as displayed in Eq. (5), a flattish start method is adopted, as is displayed in Eq. (6):

$$x[0] = [0\ 0\ \dots\ 1\ 1]^T \tag{6}$$

With the use of the flattish start method, an iterative Gauss-Newton approach is performed for the determination of a set of estimated states. In it, the matrix of Jacobian $J \in R^{m \times n}$ is reformulated in each epoch. The exiting BDD in the EMS module on the SCADA performs the remaining test of the actuarial that is shown below:

$$r = ||z - h(\hat{x})||_2 \le \tau \tag{7}$$

where $\tau$ depends on the degrees of freedom $(m - n)$ throughout the specified system, since the obtained mensuration has enough redundancy on them, the mensuration, which shows the remaining higher than $\tau$, successfully scraped as the worst possible information.

### B. Proposed Scheme

The accurate and impressive performance of the analysis based on the regression has been demonstrated by the methods of deep learning. This data-driven prediction approach has shown the onomastic error in forecasting [18], [19], [20]. The current article considers MAE, MSE and RMSE for the performance parameters that are defined below:

$$RMSE = \sqrt{\sum_{a''=1}^{b''} \frac{(f''_{a''} - s''_{a''})^2}{b''}} \tag{8}$$

$$MSE = \sum_{a''=1}^{b''} \frac{(f''_{a''} - s''_{a''})^2}{b''} \tag{9}$$

$$MAE = \sum_{a''=1}^{b''} \frac{|f''_{a''} - s''_{a''}|}{b''} \tag{10}$$

The estimated operational states with $f$, is denoted and the actual operational states with $s$ is denoted. The bald number of the instances for the estimation is $b''$. With the effective optimization of the meta-parameter, the presented neural network by the scenario of the network steady-state effectively can estimate the predicted states by the lowest value for the performance parameters. In the current article, a strong nonlinear structure of the LSTM is proposed.

The LSTM model is a particular architecture from the RNN that helps with the learning of the patterns of the complex temporal, which are provided in the dataset of the training. This particular type of RNN is able to the nature maintaining of the data at a given step of the time. Thus, the LSTM provides the possibility to read, retain, and remove the data from the memory cells by setting three distinct controllable gates, which is named the gate of the forget $g''_1(t)$, the gate of the input $j''_1(t)$ also, the gate of the output $p''_1(t)$. Fig. 1 shows the structure with the single cell for a module of LSTM. Also, the model of the presented LSTM is displayed in Fig. 2.
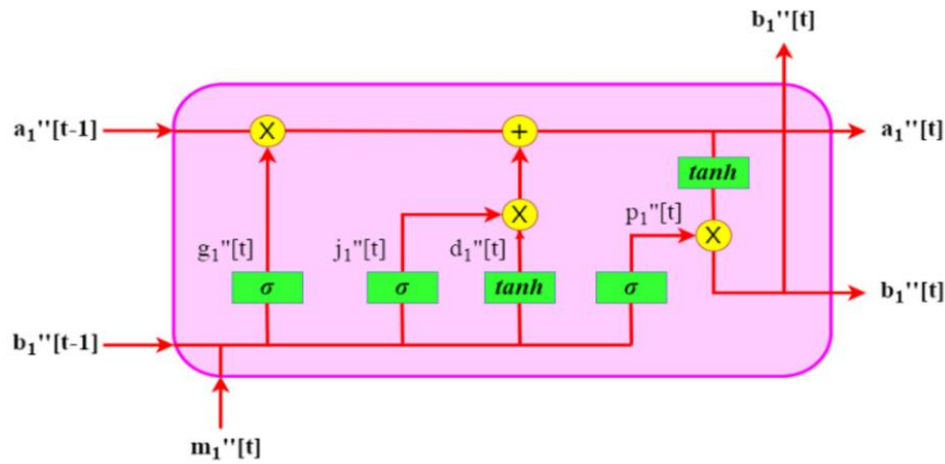
Fig. 1. Single-cell structure from an LSTM cell.
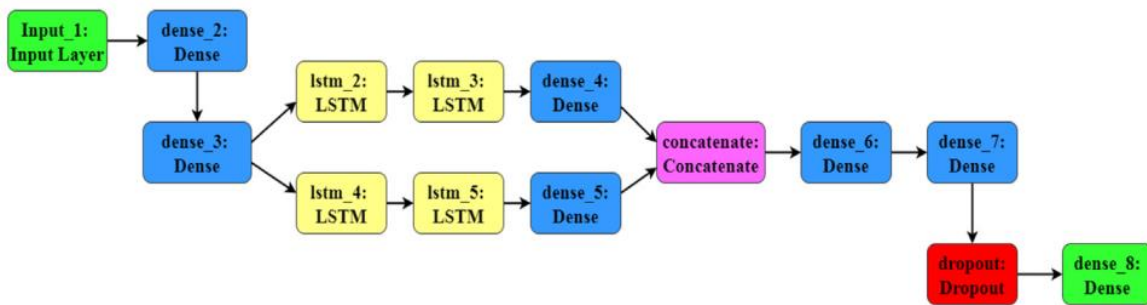


Fig. 2. The proposed LSTM model.

The admission or the rejection of the information in the form of the binary (0 or 1), which is related to the current state of the cells, depends on the gate $g''_1(t)$. The forget gate is defined by Eq. (11). On the modules of LSTM, the activation function of *sigmoid* is used. $j''_1(t)$ represents the gate of the input from the module of LSTM, which is displayed in Eq. (13). For the updation of the state of the current cell, generally, a decision of the binary by means of the gate of the input is taken. For the module of LSTM, the updated cell state is denoted with $a''_1(t)$ also, the novel contributor is $d''_1(t)$. As shown in Eq. (15), the accumulated data is discharged to the next neurons. The weights with $w''_{1(.)}$ is denoted. Also, the outputs are denoted with $b''_1(t)$, the inputs are denoted with $m''_1(t)$ and finally, the biases are denoted with $b''_{1(.)}$. These cases are shown in Eq. (11) to Eq. (16). The concatenation operation is indicated by $[.,.]$.

$$g''_1(t) = sig(w''_{1_{g''_1}}[b''_1(t-1).m''_1(t)] + b''_{1_{g''_1}}) \quad (11)$$

$$a''_1(t) = [g''_1(t) \times a''_1(t-1)] + [j''_1(t) \times d''_1(t)] \quad (12)$$

$$j''_1(t) = sig\left(w''_{1_{j''_1}}[b''_1(t-1).m''_1(t)] + b''_{1_{j''_1}}\right) \quad (13)$$

$$d''_1(t) = \tanh\left(w''_{1_{d''_1}}[b''_1(t-1).m''_1(t)] + b''_{1_{d''_1}}\right) \quad (14)$$

$$p''_1(t) = sig\left(w''_{1_{p''_1}}[b''_1(t-1).m''_1(t)] + b''_{1_{p''_1}}\right) \quad (15)$$

$$b''_1(t) = p''_1(t) \times \tanh(a''_1(t)) \quad (16)$$

Fig. 2 displays which the model of the presented LSTM has *eight* layers hidden along with one layer of the output and one layer of the input. It can be viewed that in the second layer of the hidden, the model is divided into the layers of the sub-hidden. These layers of the sub-hidden combine the structures of LSTM by the neural networks of the dense for improvement of the efficiency of the state prediction. These models of the nonlinear are found by the layers of the sub-hidden for the representation of a superior approach for the prediction. Finally, all layers of the sub-hidden are compromised in a common layer which is called the layer of the concatenation. Two layers of the dense are placed in place of the layer of the concatenation, and then the layer of the output is placed. The drop-out regularization is effectively adopted for the avoidance of the model over-inflating. The proposed nonlinear method is fed with the activation function of *ReLU* to each layer which is expressed by Eq. (17).

$$y''_{1_{i'_1}} = ReLU(w''_{1_{i'_1}} k'_{1_{i'_1}} + b'''_{1_{i'_1}}) \quad (17)$$

For layer $i'_1$, the set of predicted features is equal to $y''_{1_{i'_1}}$ and the input features are equal to $k'_{1_{i'_1}}$. Other parameters of a specific layer consist of bias $b'''_{1_{i'_1}}$ and weight $w''_{1_{i'_1}}$. The output of the layer of LSTM from the presented nonlinear method is directly entered into the next layer of the dense that this layer has the activation function of *ReLU*. The layer of the

output of this nonlinear method includes an activation function of *ReLU* according to Eq. (17). The proposed model is trained in 500 iterations and using the optimizer of *Adam*. The initial rate for the learning of the proposed method is equal to 0.001.

By effectively training the model, a superior policy can be demonstrated for the estimation of states by the indices of the minimum error. The scheme of the real-time FDI attack recognition, which is the basis of the matrix of the error covariance, is presented in Fig. 3. The algorithm of the presented anomaly detection performs the vector of the

developed error according to the predicted operational states and predicted operational states in the SCADA.

$$e(t) = \hat{x}_{for}(t) - \hat{x}_{test}(t) \qquad (18)$$

$\hat{x}_{for}(t) \in R^n$ represents the predicted set from the estimated states, which is obtained by the benchmark of the scalable nonlinear neural network and $\hat{x}_{test}(t) \in R^n$ represents the predicted states of the step of the time $t$, which are recovered with the use of the algorithm of the state prediction. Also, $e(t) \in R^n$ represents the error vector.
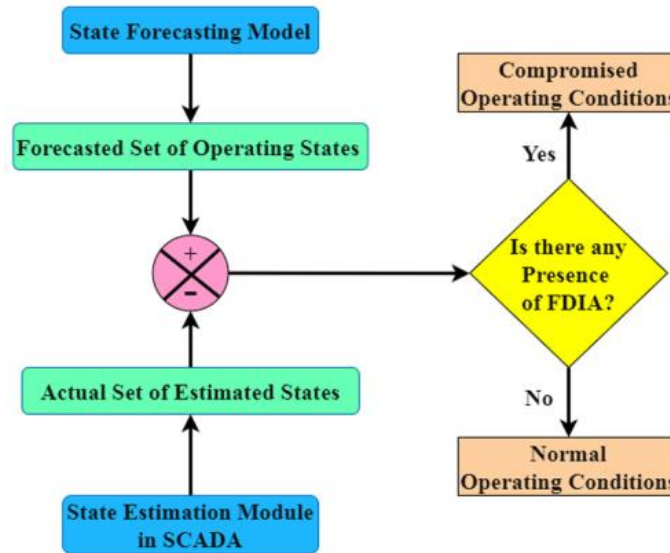


Fig. 3. The proposed method for the detection of the attack of FDI.

The main purpose of the method of anomaly recognition is the identification of the eigenvalues change rate of the matrix of the error covariance, which is displayed as follows:

$$\frac{d\mu}{dt} = x_1^T(t)\frac{dE(t)}{dt}x_1(t) \qquad (19)$$

$$\frac{dE}{dt} \approx \frac{E(t) - E(t - \delta t)}{\delta t} \qquad (20)$$

$x_1(t) \in R^n$ represents the eigenvector for the matrix of the error covariance $E(t) \in R^{n \times n}$ which is generated pending the time of the current sampling $t$. Since $E(t)$ and $E^T(t)$ are the matrices of the symmetric positive definite covariance. Therefore, these matrices have the same eigenvalues and the same eigenvectors. The change rate of the eigenvalues among two intervals of the consecutive time $t$ and $(t - \delta t)$ can be shown by Eq. (19) and Eq. (20), respectively. The proposed detection scheme for the FDI attack that performs the change rate of eigenvalues is described as follows:

$$\varepsilon = \begin{cases} 1 & \frac{d\mu}{dt} > RMSE + \delta_1 \\ 0 & otherwise \end{cases} \qquad (21)$$

where $\varepsilon$ displays the criterion of the recognition that is adjusted with 1. Thus, if the change rate of eigenvalues in a specific time $t$ exceeds a particular threshold, as is displayed in Eq. (21), it shows the presence of the FDI attack inside the obtained measurements. $\delta_1$ displays a numerical constant with a very small positive value which belongs to the operator

knowledge. This parameter inherently is insignificant because the model of the nonlinear state prediction shows better accuracy for prediction.

## IV. EVALUATION RESULTS OF THE PROPOSED METHOD

In this section, the results of the evaluation of the presented method are examined. First, the used dataset is described. In the following, the results of the proposed deep learning method for the prediction of RUL are evaluated. Then, the continuous and temporary signatures from the FDI attack are provided, and then the attack's impact on the prediction of RUL is stated. The Python programming language has been used for the implementation of these tests. The presented method is implemented on a computer which has a Core (TM) i7 CPU, 3.0 GHz Intel(R) and 8G RAM.

### A. Used Dataset

For the performance evaluation of the presented method, the dataset of the NASA C-MAPSS turbofan engine destruction simulation is used. The used dataset consists of 21 data of the sensor by the number of the conditions of the operational and the conditions of the different error. On the used dataset, four subsets (FD001-04) are defined. Each subset includes the data from the training and the data from the test. The data of the test is reached to the data of the defeat from the multiple engines with the same group. In the data of the test, each row is a cycle of time that is defined as one hour of working. A cycle of time has 26 columns which column 1

displays the ID of the engine and column 2 displays the number of cycles of the current operation. Columns 3 to column 5 display the three settings of the operational and also, the columns 6 to column 26 display the 21 values of the sensor. The data of the time series is only terminated when it encounters an error. The data of the test consist of only the information for some cycles of the time because our purpose is the estimation of the cycles of the time of the remaining operational before the occurrence of a defect.

### B. Results of the Proposed Method of RUL Prediction

For the confirmation of the proper efficiency of the presented algorithm, which is the basis of the LSTM, this method has been evaluated on the dataset of C-MAPSS. For the performance evaluation of predictors, RMSE, MSE and MAE are used. These metrics are widely used as the criteria of evaluation in the studies of the evaluation of the model. The results are related to the network, which this network has 100 nodes in the layers hidden from the first layer. In addition, it has 100 nodes in the layers hidden from the second layer and 100 nodes in the layers hidden from the third layer.

Furthermore, the length of its sequence is equal to 80. Table I shows the meta-parameters of the proposed LSTM model (inspired by [21]). Fig. 4 shows the performance results of the presented method. Also, Table II shows the results of the error evaluation for the presented method and the similar presented methods in [22], [23] and [24].

TABLE I.    THE HYPER-PARAMETERS SETTINGS OF THE PRESENTED LSTM MODEL

| Model | Hidden Neuron | Dro-pout | Batch Size | Epochs | Activation Function |
|---|---|---|---|---|---|
| LSTM | 100 | 0.2 | 200 | 100 | ReLU |
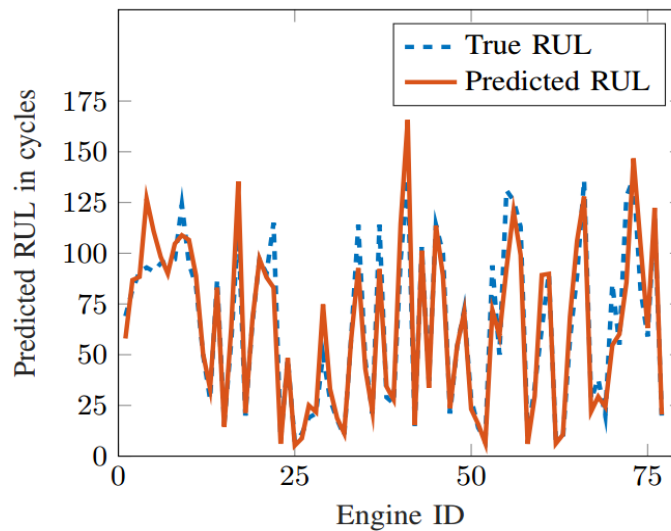


Fig. 4.   The comparison results of the prediction of RUL by the proposed scheme and the actual RUL value.

TABLE II.    THE COMPARISON RESULTS BETWEEN THE PRESENTED METHOD AND THE SIMILAR METHODS

| Model | RMSE | MSE | MAE |
|---|---|---|---|
| Proposed LSTM | 6.948 | 3.241 | 132.894 |
| Proposed in [22] | 7.422 | 5.022 | 145.488 |
| Proposed in [23] | 9.711 | 8.925 | 150.961 |
| Proposed in [24] | 13.324 | 10.052 | 166.922 |

It is evident from Fig. 4 and Table II that the proposed algorithm with a sequence length equal to 80 has the lowest amount of error. This means that the presented method is very precise about the prediction of RUL on the used dataset. It should be noted that the displayed results in Table II state that the prediction method basis on LSTM does much better than the presented works on [22], [23] and [24]. In the next stage, the attack of FDI in the proposed LSTM-based method is modeled for the evaluation of their resilience against the attack of FDI.

### C. Modeling Two FDI Attack Scenarios and the Impact Examination of these Attacks in RUL Prediction

The average engine degradation point $N_{avg}^d$, for the FD001 dataset, is taken to be 130 [25]. It is assumed that the system of the monitoring dispatches 20 cycles of the time ($N_b$) from the data to the side of the ground. The dataset of the training and the dataset of the test have 21 data of the sensor. The attack of FDI is performed in 21 sensors. However, for the creation of the realistic attack, the FDI attack only in *three* sensors ($T24$, $P30$ and $T50$) is performed. The details of 21 sensors are provided in [26]. On the first FDI attack scenario,

i.e. the scenario of the continuous, the attacker has begun the attacks since $N_{avg}^d$ (that is equal to 130-time cycles) and the duration of the attacks is up to the engine life's end. In the second scenario of an FDI attack, i.e. scenario temporary, the attacker has begun the attacks since $N_{avg}^d$ (that is equal to 130 cycles of time). The duration of these attacks is 20 hours. With respect to the attack begins, since 130 cycles of the time, only the engines with data greater than 130 cycles are considered. In the FD001 dataset, the number of these engines is equal to 37. The resulting dataset is re-appraised with the use of the proposed LSTM-based model. The obtained values for RMSE, MSE and MAE are respectively equal to 20.651, 10.236 and 159.415.

To model the FDI attack on the sensors, a null vector is added to the main vector that changes the output of the sensor with a so little border equal to 0.01% to 0.05% for a random

FDI attack and equal to 0.02% for a biased FDI attack. Here, the random FDI attack means that the added noise to the output of the sensor has a span equal to 0.01% to 0.05%. At the same time, the biased FDI attack adds a fixed noise value to the output of the sensor. Fig. 5 displays a collation of the signal of the output of the main FDI attack and the signal of the output of the biased FDI attack from the second sensor for the engine with an ID equal to 3. On the continuous attack of FDI, the output of the sensor from 130 cycles of time up to the engine life end is attacked. In the case of a biased attack of FDI for a period of the temporary, similar to Fig. 6, the duration of the attack only is 20 cycles of the time (130 cycles of the time to 150 cycles of the time). Be careful; on the limited attack, the attacker has restricted accessibility to the sensors. Similar to Fig. 5 and Fig. 6, the attack signature is very analogous to the main signal. Its detection makes it hard even with the common defense mechanisms.
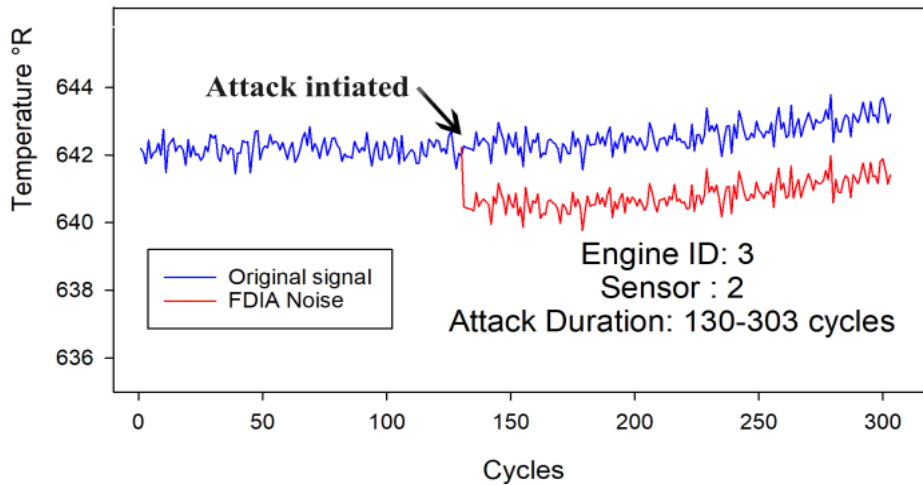


Fig. 5.   The continuous FDI attack signature.
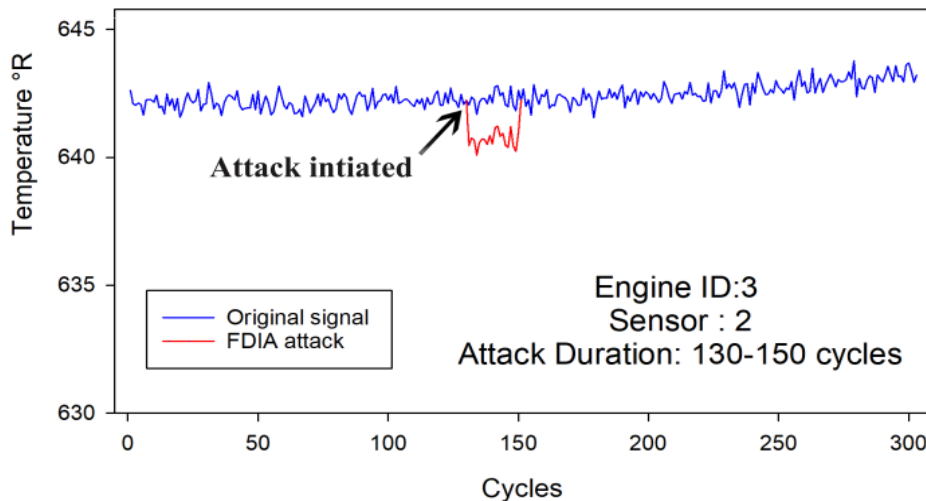


Fig. 6.   The temporary FDI attack signature.

Now, the effect of the scenarios of the attack of FDI on the proposed LSTM-based method is investigated. To demonstrate the effect of attack of the attack of FDI on the system of monitoring, an attack by the mentioned scenario is ran. The FDI attack in three sensors ($T24$, $P30$ and $T50$) is

performed instead of the attack in all 21 sensors of the dataset. In the scenario of the continuous FDI attack, the attacker makes the attacks from 130 cycles of time until the end of the engine life. It is clear from Fig. 7 that the proposed LSTM-based method is greatly affected by the continuous attack of

FDI. About the fortuitous FDI attack and the biased FDI attack, the random FDI attack has shown a significant impact on the proposed LSTM-based model. Table III shows the relevant results.

In the scenario of the temporary FDI attack, the attacker makes the attacks between 130 cycles of time and 150 cycles of time. It is clear from Fig. 8 that the proposed LSTM-based method is greatly affected by the temporary attack of FDI. Table IV shows the relevant results. With the comparison between the continuous FDI attack and the temporary FDI attack, it can be seen that the error of a continuous attack of FDI is almost twice the error of a temporary attack of FDI. Hence, continuous FDI attacks are stronger than temporary FDI attacks.

*D. Discussion*

In this work, the proposed method is evaluated on the dataset of C-MAPSS, and the obtained results show the great prospects for deep learning in PdM. It is also observed that sequence length and network architecture are very important in accurately predicting RUL. The proposed work shows that the proposed method is several times better than recent works that use deep learning on the dataset of C-MAPSS. The analysis of the impact of an FDI attack on aircraft sensors in the dataset of CMAPSS provides interesting insights. It is observed that the CNN-based model is strongly affected by random and biased FDI. In the case of temporary FDI, the random and biased RMSE of CNN is several times higher than

the true RMSE, and in the case of continuous, the random and biased RMSE is several times higher than the true RMSE. Also, it is observed that the CNN-based model is more flexible in both random and biased cases in compared to other models. In the case of temporary attack, the random and biased RMSE is several times higher than the true RMSE, which makes it disastrous for the PdM system. This may lead to delays in timely maintenance of the aircraft engine and ultimately lead to engine failure in some cases.

Note, the FDI attack signature is very close to the original sensor output, which makes it more difficult to detect by common defense mechanisms in the engine health monitoring system. A piecewise prediction approach is used in visualizing the impact of attacks on sensors, which clearly shows that the PdM system is susceptible to sensor attacks. The CNN-based prediction results show that special measures should be taken when designing and by using PdM systems because they are very sensitive to FDI. Such an analysis can serve as empirical guidance for the development of subsequent data-driven PdM systems. All these obtained results show that DL-based PdM systems have good prospects for aircraft maintenance; however, they are highly susceptible to sensor attacks. Hence, it is necessary to explore suitable detection techniques to identify such stealth attacks and special care should be taken when building IoT sensors for DL/AI applications. For this reason, when designing a PdM system, the designer should also consider the flexibility of the DL algorithm instead of emphasizing the accuracy of the algorithm.

TABLE III.    THE RELEVANT RESULTS TO THE SCENARIO OF THE CONTINUOUS ATTACK OF FDI

| Model | RMSE | MSE | MAE |
|---|---|---|---|
| Model Under Random FDI Attack | 50.325 | 25.614 | 1036.234 |
| Model Under Biased FDI Attack | 37.512 | 19.512 | 797.328 |
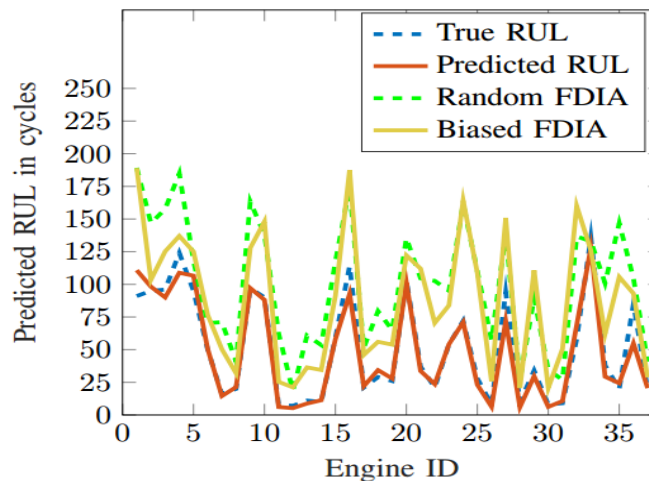


Fig. 7.   The relevant results to the RUL prediction in the scenario of the continuous attack of FDI.

TABLE IV.    THE RELEVANT RESULTS TO THE TEMPORARY FDI ATTACK SCENARIO

| Model | RMSE | MSE | MAE |
|---|---|---|---|
| Model Under Random FDI Attack | 27.651 | 14.351 | 548.678 |
| Model Under Biased FDI Attack | 19.547 | 10.985 | 410.365 |
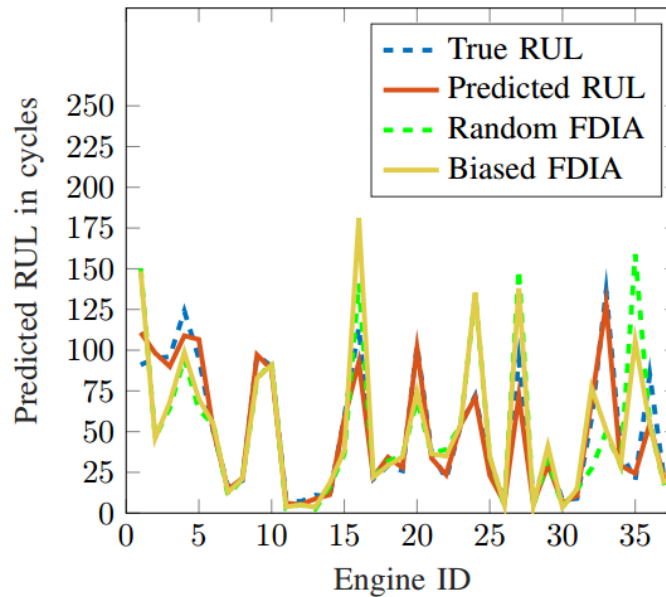
Fig. 8. The relevant results to the RUL prediction in the temporary FDI attack scenario.

## V. CONCLUSIONS AND SUGGESTIONS

With the expansion of the use of cyber-physical structures and communication networks, cyberattacks have become a serious threat in various networks, including the sensors of the Internet of Things. These attacks create the so assailable conditions. Therefore, the main consideration of this current paper is the detection in real-time of the done FDI attack on the Internet of Things, which is related to the estimated RUL prediction. The robust and nonlinear structure of the LSTM shows a better view of the RUL prediction compared to similar methods. The method of the presented nonlinear LSTM is successfully implemented in real-time because the efficiency of its computational (the time of the test and the time of the training) is on the scope of the microseconds. In the future, the method of the presented detection can be performed by the scenarios of the contingency of the smart networks and by a more intransigent constraint on the criterion of detection, which ultimately results in a stronger feasibility of the FDI attack detection. Also, an end-to-end method can be developed for the recognition and reduction of attacks on the sensor in a system of network health monitoring.

## REFERENCES

[1] K. Alnowibet, A. Annuk, U. Dampage, and M. A. Mohamed, "Effective energy management via false data detection scheme for the interconnected smart energy hub–microgrid system under stochastic framework," Sustainability, vol. 13, no. 21, p. 11836, 2021.

[2] M. A. der Mauer, T. Behrens, M. Derakhshanmanesh, C. Hansen, and S. Muderack, "Applying sound-based analysis at porsche production: Towards predictive maintenance of production machines using deep learning and internet-of-things technology," Digitalization cases: How organizations rethink their business for the digital age, pp. 79–97, 2019.

[3] A. K. Sikder, G. Petracca, H. Aksu, T. Jaeger, and A. S. Uluagac, "A survey on sensor-based threats to internet-of-things (iot) devices and applications," arXiv preprint arXiv:1802.02041, 2018.

[4] D. An, Q. Yang, W. Liu, and Y. Zhang, "Defending against data integrity attacks in smart grid: A deep reinforcement learning-based approach," IEEE Access, vol. 7, pp. 110835–110845, 2019.

[5] K. Manandhar, X. Cao, F. Hu, and Y. Liu, "Detection of faults and attacks including false data injection attack in smart grid using Kalman filter," IEEE Trans Control Netw Syst, vol. 1, no. 4, pp. 370–379, 2014.

[6] D. An, F. Zhang, Q. Yang, and C. Zhang, "Data integrity attack in dynamic state estimation of smart grid: Attack model and countermeasures," IEEE Transactions on Automation Science and Engineering, vol. 19, no. 3, pp. 1631–1644, 2022.

[7] Y. An and D. Liu, "Multivariate Gaussian-based false data detection against cyber-attacks," IEEE Access, vol. 7, pp. 119804–119812, 2019.

[8] K. Arulkumaran, M. P. Deisenroth, M. Brundage, and A. A. Bharath, "A brief survey of deep reinforcement learning," arXiv preprint arXiv:1708.05866, 2017.

[9] G. Liang, J. Zhao, F. Luo, S. R. Weller, and Z. Y. Dong, "A review of false data injection attacks against modern power systems," IEEE Trans Smart Grid, vol. 8, no. 4, pp. 1630–1638, 2016.

[10] B. Li, R. Lu, W. Wang, and K.-K. R. Choo, "Distributed host-based collaborative detection for false data injection attacks in smart grid cyber-physical system," J Parallel Distrib Comput, vol. 103, pp. 32–41, 2017.

[11] Y. Guan and X. Ge, "Distributed attack detection and secure estimation of networked cyber-physical systems against false data injection attacks and jamming attacks," IEEE Trans Signal Inf Process Netw, vol. 4, no. 1, pp. 48–59, 2017.

[12] A. Ashok, M. Govindarasu, and V. Ajjarapu, "Online detection of stealthy false data injection attacks in power system state estimation," IEEE Trans Smart Grid, vol. 9, no. 3, pp. 1636–1646, 2016.

[13] N. I. Haque et al., "A survey of machine learning-based cyber-physical attack generation, detection, and mitigation in smart-grid," in 2020 52nd North American Power Symposium (NAPS), IEEE, 2021, pp. 1–6.

[14] A. Abur and A. G. Exposito, Power system state estimation: theory and implementation. CRC press, 2004.

[15] Y. Liu, P. Ning, and M. K. Reiter, "False data injection attacks against state estimation in electric power grids," ACM Transactions on Information and System Security (TISSEC), vol. 14, no. 1, pp. 1–33, 2011.

[16] F. Wen and W. Liu, "An efficient data-driven false data injection attack in smart grids," in 2018 IEEE 23rd International Conference on Digital Signal Processing (DSP), IEEE, 2018, pp. 1–5.

[17] J. Kim, L. Tong, and R. J. Thomas, "Subspace methods for data attack on state estimation: A data driven approach," IEEE Transactions on Signal Processing, vol. 63, no. 5, pp. 1102–1114, 2014.

[18] D. Mukherjee, S. Chakraborty, P. K. Guchhait, and J. Bhunia, "Machine learning based solar power generation forecasting with and without MPPT controller," in 2020 IEEE 1st International Conference for Convergence in Engineering (ICCE), IEEE, 2020, pp. 44–48.

[19] D. Mukherjee, S. Chakraborty, P. K. Guchhait, and J. Bhunia, "Application of machine learning for speed and torque prediction of pms motor in electric vehicles," in 2020 IEEE 1st International Conference for Convergence in Engineering (ICCE), IEEE, 2020, pp. 129–133.

[20] D. Mukherjee and S. Chakraborty, "A deep learning approach for an effective speed and torque forecasting policy of PMS motors in electric vehicles," in 2022 second international conference on power, control and computing technologies (ICPC2T), IEEE, 2022, pp. 1–6.

[21] A. L. Ellefsen, E. Bjørlykhaug, V. Æsøy, S. Ushakov, and H. Zhang, "Remaining useful life predictions for turbofan engine degradation using semi-supervised deep architecture," Reliab Eng Syst Saf, vol. 183, pp. 240–251, 2019.

[22] D. Mukherjee, S. Chakraborty, R. Banerjee, and J. Bhunia, "A novel real-time false data detection strategy for smart grid," in 2021 IEEE 9th Region 10 Humanitarian Technology Conference (R10-HTC), IEEE, 2021, pp. 1–6.

[23] D. Mukherjee, S. Chakraborty, R. Banerjee, J. Bhunia, and P. K. Guchhait, "A novel deep learning framework to identify false data injection attack in power sector," in TENCON 2021-2021 IEEE Region 10 Conference (TENCON), IEEE, 2021, pp. 278–283.

[24] D. Mukherjee and S. Chakraborty, "Real-time identification of false data injection attack in smart grid," in 2021 IEEE Region 10 Symposium (TENSYMP), IEEE, 2021, pp. 1–6.

[25] F. O. Heimes, "Recurrent neural networks for remaining useful life estimation," in 2008 international conference on prognostics and health management, IEEE, 2008, pp. 1–6.

[26] D. K. Frederick, J. A. DeCastro, and J. S. Litt, "User's guide for the commercial modular aero-propulsion system simulation (C-MAPSS)," 2007.

[27] A. Xu, et al., "Research on false data injection attack in smart grid," in IOP Conf. Series: Earth and Environmental Science, Proc. 8th Annual Int. Conf. on Geo-Spatial Knowledge and Intelligence, vol. 693, Article ID: 012010, Xi'an, Shaanxi, China, 18-19 Dec. 2020.

[28] Q. Zhang et al., "Profit-oriented false data injection on energy market: reviews, analyses and insights," IEEE Trans. on Industrial Informatics, vol. 17, no. 9, pp. 5876-5886, Sept. 2020.

[29] L. Xie, Y. Mo, and B. Sinopoli, "Integrity data attacks in power market operations," IEEE Trans. on Smart Grid, vol. 2, no. 4, pp. 659-666, Dec. 2011.

[30] B. Jin, C. Dou, and D. Wu, "False data injection attacks and detection on electricity markets with partial information in a micro - grid - based smart grid system," International Trans. on Electrical Energy Systems, vol. 30, no. 12, Article ID: e12661, Dec. 2020.

[31] L. Jia, R. J. Thomas, and L. Tong, "Malicious data attack on realtime electricity market," in Proc. IEEE In. Conf. on Acoustics, Speech and Signal Processing, ICASSP'11, pp. 5952-5955, Prague, Czech Republic, 22-27 May 2011.

[32] Y. Yuan, Z. Li, and K. Ren, "Modeling load redistribution attacks in power systems," IEEE Trans. on Smart Grid, vol. 2, no. 2, pp. 382- 390, Jun. 2011.

[33] B. Huang, Y. Li, F. Zhan, Q. Sun, and H. Zhang, "A distributed robust economic dispatch strategy for integrated energy system considering cyber-attacks," IEEE Trans. on Industrial Informatics, vol. 18, no. 2, pp. 880-890, Feb. 2021.

[34] R. Tan, V. Badrinath Krishna, D. K. Yau, and Z. Kalbarczyk, "Impact of integrity attacks on real-time pricing in smart grids," in Proc. of the ACM SIGSAC Conf. on Computer & Communications Security, pp. 439-450, Berlin, Germany, 4-8 Nov. 2013.

[35] M. Tian, Z. Dong, and X. Wang, "Analysis of false data injection attacks in power systems: a dynamic Bayesian game-theoretic approach," ISA Trans., vol. 115, pp. 108-123, Sept. 2021.

[36] M. Esmalifalak, G. Shi, Z. Han, and L. Song, "Bad data injection attack and defense in electricity market using game theory study," IEEE Trans. on Smart Grid, vol. 4, no. 1, pp. 160-169, Mar. 2013.

[37] C. Jin, Z. Bao, M. Yu, J. Zheng, and C. Sha, "Optimization of joint cyber topology attack and FDIA in electricity market considering uncertainties," in Proc. IEEE Power & Energy Society General Meeting, PESGM'21, 5 pp., Washington, DC, USA, 26-29 Jul. 2021.

[38] D. H. Choi and L. Xie, "Economic impact assessment of topology data attacks with virtual bids," IEEE Trans. on Smart Grid, vol. 9, no. 2, pp. 512-520, Mar. 2018.

[39] H. Xu, Y. Lin, X. Zhang, and F. Wang, "Power system parameter attack for financial profits in electricity markets," IEEE Trans. on Smart Grid, vol. 11, no. 4, pp. 3438-3446, Jul. 2020.

[40] K. Lai, M. Illindala, and K. Subramaniam, "A tri-level optimization model to mitigate coordinated attacks on electric power systems in a cyber-physical environment," Applied Energy, vol. 235, pp. 204-218, Feb. 2019.

[41] P. K. Jena, S. Ghosh, and E. Koley, "A binary-optimization-based coordinated cyber-physical attack for disrupting electricity market operation," IEEE Systems J., vol. 15, no. 2, pp. 2619-2629, Jun. 2020.

[42] P. K. Jena, S. Ghosh, E. Koley, D. K. Mohanta, and I. Kamwa, "Design of AC state estimation based cyber-physical attack for disrupting electricity market operation under limited sensor information," Electric Power Systems Research, vol. 205, Article ID: 107732, Apr. 2022.

[43] M. Esmalifalak, et al., "A stealthy attack against electricity market using independent component analysis," IEEE Systems J., vol. 12, no. 1, pp. 297-307, Mar. 2018.

[44] S. Tan, W. Z. Song, M. Stewart, J. Yang, and L. Tong, "Online data integrity attacks against real-time electrical market in smart grid," IEEE Trans. on Smart Grid, vol. 9, no. 1, pp. 313-322, Jan. 2018.

[45] A. Tajer, "False data injection attacks in electricity markets by limited adversaries: stochastic robustness," IEEE Trans. on Smart Grid, vol. 10, no. 1, pp. 128-138, Jan. 2019.

# Automated Fruit Grading in Precise Agriculture using You Only Look Once Algorithm

Weiwei Zhang

Henan Polytechnic Institute, Nanyang Henan 473000, China

*Abstract*—In the realm of precision agriculture, the automated grading of fruits stands as a critical endeavor, serving to maintain consistent quality assessment and streamline the sorting process. Traditional methods based on computer vision and deep learning techniques have both been explored extensively in the context of fruit grading, with the latter gaining prominence due to its superior performance. However, the existing research landscape in the domain of deep learning-based fruit grading confronts a compelling challenge: striking a balance between accuracy and computational cost. This challenge has been consistently noted through an extensive analysis of prior studies. In response, this study introduces an innovative approach built upon the YOLOv5 algorithm. This methodology encompasses the creation of a bespoke dataset and the division of data into training, validation, and testing sets, facilitating the training of a robust and computationally efficient model. The findings of the experiments and the subsequent performance evaluation underscore the effectiveness of the proposed method. This approach yields significant improvements in both accuracy and computational efficiency, thus addressing the ongoing challenge in deep learning-based fruit grading. Therefore, this study contributes valuable insights into the field of automated fruit grading, offering a promising solution to the trade-off between accuracy and computational cost while demonstrating the practical viability of the YOLOv5-based approach.

*Keywords—Precise agriculture; automated fruit grading; deep learning; computer vision; Yolov5*

## I. INTRODUCTION

In recent years, the field of precise agriculture has gained significant attention due to its potential to revolutionize traditional farming practices by incorporating advanced technologies for improved crop management [1, 2]. One crucial aspect of precise agriculture is automated fruit grading, which plays a vital role in ensuring consistent quality assessment and efficient sorting of fruits [2, 3]. Automated fruit grading systems leverage computer vision and machine learning techniques to analyze fruit characteristics and assign appropriate grades, reducing the reliance on manual labor and improving productivity.

The integration of video-based technologies has emerged as a promising approach for object detection, tracking and specifically for automated fruit grading [4-6]. Video-based systems capture a continuous stream of fruit images, allowing for more comprehensive analysis and enabling real-time grading and sorting [7-9]. These technologies have shown great potential in enhancing the accuracy and efficiency of fruit grading systems, leading to improved productivity and quality control [10].

Despite the advancements in video-based technologies, there are still challenges that need to be addressed in the field of automated fruit grading [11, 12]. Existing methods often rely on traditional image processing techniques and rule-based algorithms, which may not fully capture the complex features and variations present in fruits [4]. This limitation has led to a growing interest in deep learning-based methods, particularly convolutional neural networks (CNNs) [13-15], which have demonstrated remarkable capabilities in image analysis tasks. Deep learning approaches offer the potential for more accurate and robust fruit grading systems capable of handling diverse fruit types and variations.

Previous studies have shown the effectiveness of deep learning-based methods in automated fruit grading. These methods have been successful in capturing fine-grained features and patterns, leading to improved accuracy rates compared to traditional approaches [11, 16]. However, existing research primarily focuses on high computational costs and may not address the requirements of low computational resources, which are often present in practical agricultural settings [17]. This research gap presents an opportunity to develop lightweight deep-learning models that can balance computational efficiency with high accuracy rates.

This paper aims to address the aforementioned research gap by proposing a lightweight deep-learning approach based on YOLO (You Only Look Once) algorithms for automated fruit grading in precise agriculture. This study leverages a custom dataset of fruit images and employ a training, validation, and testing process to generate a robust and efficient model. The research contributions include identifying the research gap in low computational cost and high accuracy rate requirements, proposing a lightweight deep learning-based method to address the limitation, and conducting comprehensive experimental and performance evaluations to validate the effectiveness of the proposed approach.

The main research contributions of this study are as follows:

### A. Identification of Research Gap

The paper identifies the research gap in the field of automated fruit grading regarding the requirements of low computational cost and high accuracy rates. By recognizing this gap, the paper aims to address the limitations of existing methods and propose a solution that satisfies these specific requirements.

## B. *Proposal of a Lightweight Deep Learning Approach*

The paper proposes a lightweight deep learning-based method for automated fruit grading using YOLO algorithms. This approach takes into consideration the need for computational efficiency while maintaining high accuracy rates. By leveraging YOLO algorithms, the proposed method aims to achieve real-time fruit grading with optimal resource utilization.

## C. *Comprehensive Experimental and Performance Evaluations*

The paper conducts thorough experimental and performance evaluations to validate the effectiveness of the proposed approach. By utilizing a custom dataset of fruit images and employing a rigorous training, validation, and testing process, the paper demonstrates the robustness and efficiency of the generated model. These evaluations provide empirical evidence of the accuracy and effectiveness of the proposed method in addressing the identified research gap.

The reminding of this paper is as follows, related works review in Section II. Methodology discusses in Section III. Section IV presents results and discussion. Finally, the paper concludes in Section V.

## II. RELATE WORKS

The paper in [18] developed the classification and grading of Okra-ladies fingers using deep learning techniques. The research challenge addressed in the paper is to develop an efficient and accurate system for automated classification and grading of Okra-ladies' fingers based on their quality attributes. The proposed approach utilizes deep learning models, specifically convolutional neural networks (CNNs), to analyze the visual features of Okra-ladies finger images. The CNN model is trained on a large dataset of labeled Okra-ladies finger images to learn the patterns and characteristics associated with different quality grades. Experimental results demonstrate the effectiveness of the deep learning-based approach in accurately classifying and grading Okra-ladies' fingers. The system's performance is evaluated using metrics such as accuracy, precision, and recall, showing promising results in achieving reliable quality assessment in an automated manner. The proposed system offers potential applications in the food industry, facilitating efficient sorting and quality control processes for Okra-ladies finger production.

Ismail and Malik [19] presented a real-time visual inspection system for grading fruits using computer vision and deep learning techniques. The research challenge addressed in the paper is to develop an efficient and accurate system that can automatically grade fruits based on their quality attributes. The proposed system leverages computer vision algorithms and deep learning models to analyze fruit images and classify them into grades or categories in real-time. By combining advanced image processing techniques with deep learning, the system achieves high accuracy and enables fast and automated fruit grading, providing an effective solution for quality control in the fruit industry.

Patil et al. [20] presented a grading and sorting technique for dragon fruits using machine learning algorithms. The research challenge addressed in the paper is to develop a reliable and efficient system that can automatically grade and sort dragon fruits based on their quality attributes. The proposed technique utilizes machine learning algorithms, including decision trees and support vector machines, to analyze the visual features of dragon fruit images and classify them into different grades. The system is trained on a dataset of labeled dragon fruit images to learn the patterns and characteristics associated with each grade. Experimental results demonstrate the effectiveness of the machine learning-based approach in accurately grading and sorting dragon fruits. The proposed technique offers a practical solution for the fruit industry, enabling automated and consistent quality assessment for dragon fruit production.

Chakraborty et al. [21] focused on developing an optimally designed real-time automatic citrus fruit grading-sorting machine by leveraging a computer vision-based adaptive deep learning model. The research challenge addressed in the paper is to create a machine that can accurately grade and sort citrus fruits in real-time. The proposed system utilizes computer vision techniques and adaptive deep learning models to analyze fruit images and classify them according to quality attributes such as size, color, and shape. By combining these advanced technologies, the machine achieves high accuracy and efficiency in citrus fruit grading and sorting, offering a practical solution for the citrus industry's quality control and productivity enhancement.

## III. METHODOLOGY

To propose a YOLOv5-based model for automated fruit grading and sorting using a custom dataset of 544 images, the details of the methodology discuss as follows:

### A. *Data Pre-processing*

In the data pre-processing step, the first task is to split the dataset of fruit images into three distinct sets: training, validation, and testing. This split is done using the specified ratios of 70%, 20%, and 10% for training, validation, and testing sets, respectively. By dividing the dataset in this manner, it is ensured that the model is trained on a substantial portion of the data while retaining separate sets for evaluation.

Next, it is crucial to shuffle the dataset randomly. This randomization ensures that the fruit images are distributed across the different sets in a diverse manner. By avoiding any specific order or patterns in the dataset, it reduced the risk of introducing biases into the model during training and evaluation.

Furthermore, various pre-processing steps are applied to the fruit images. Firstly, the images are resized to a consistent size to meet the requirements of the YOLOv5 model, typically around 416x416 pixels. This standardization facilitates efficient processing and consistent results. Additionally, pixel values are normalized to a common scale, often within the range of [0, 1]. Normalization aids in improving the convergence and stability of the training process.

Lastly, bounding boxes need to be annotated around the fruits in the images. These annotations provide the necessary training labels for the YOLOv5 model to learn object

detection. By defining the precise locations of the fruits within the images, the model can be trained to accurately detect and classify the fruits during the subsequent training phase.

### B. Model Architecture

The YOLOv5 model represents an advanced object detection approach built on a convolutional neural network (CNN) architecture. This model has demonstrated outstanding performance in real-time object detection tasks, making it an excellent choice for automated fruit grading and sorting. To begin implementing YOLOv5 for our project, we need to access the official YOLOv5 repository hosted on GitHub. By navigating to the repository at https://github.com/ultralytics/yolov5, it can clone the entire codebase to our local development environment. This step is essential as it provides all the necessary files, scripts, and resources needed for training and utilizing the YOLOv5 model. Fig. 1 illustrates the YOLOv5 model architecture [22].
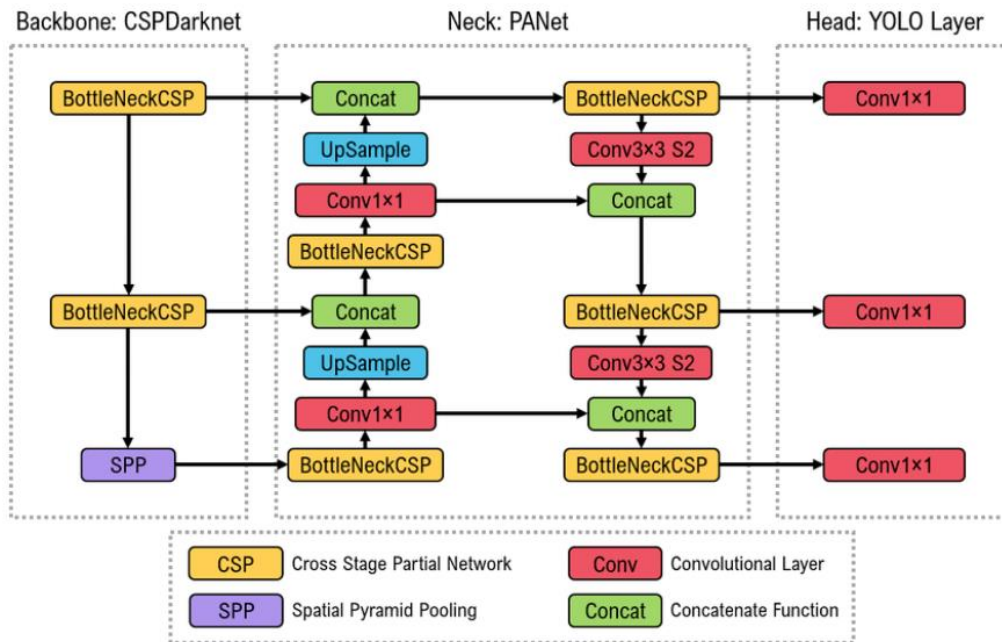


Fig. 1. The YOLOv5 model architecture [22].

With the YOLOv5 repository successfully cloned to the local environment, it is possible to proceed to tailor the model to our specific fruit grading and sorting task. One critical aspect of customization involves modifying the YOLOv5 configuration file. This file allows us to configure various aspects of the model, accommodating our dataset's unique characteristics and requirements. Among the customizable parameters are the number of classes to be detected and sorted, which would be the different fruit types or grades in this context. Additionally, it can adjust settings such as the input image size, the architecture of the underlying neural network, and training hyperparameters.

Customizing the YOLOv5 configuration file ensures that the model is designed to recognize the specific fruit types and grading categories present in our dataset accurately. Fine-tuning these parameters allows the YOLOv5 model to be tailored precisely to our use case, maximizing its performance and enhancing the accuracy of the fruit grading and sorting process. By configuring the model in this manner, it enables to identify and classify fruits based on their unique characteristics, providing us with a powerful tool for automating the grading and sorting tasks with efficiency and precision.

In the implementation process for training a YOLOv5 model for fruit grading, the first step involves partitioning the dataset into a training set, which constitutes 70% of the total data, containing images and their corresponding annotated bounding boxes. Next, the YOLOv5 model is configured by utilizing a modified configuration file specifying parameters such as the number of classes, input image size, and network architecture, and the training data is pre-processed, including resizing images, normalizing pixel values, and incorporating annotated bounding boxes. The model is initialized with random weights before training commences. To facilitate training for object detection, an appropriate loss function, like YOLOv5 Loss or GIoU Loss, is selected to quantify the disparity between predicted bounding boxes and ground truth annotations. An optimizer, such as SGD or Adam, is used to update the model's weights based on the computed loss. During training iterations, data is fed to the model in batches with batch size selection depending on available computational resources, typically ranging from 8 to 32. The number of training epochs is chosen for convergence and desired model performance. The forward pass predicts bounding box coordinates, objectness scores, and class probabilities, while the backward pass calculates the loss and uses backpropagation to adjust the model's parameters for minimizing discrepancies. The training process is closely monitored by tracking metrics like loss and accuracy, which can be visualized using tools like TensorBoard, allowing for analysis and fine-tuning of the

model's training process to ensure accurate fruit grading based on the learned criteria.

*C. Model Training*

During the training process for fruit grading and sorting using the YOLOv5 model, several key steps are involved. Here's an explanation of each step:

*1) Training set usage:* The training set, which accounts for 70% of the total dataset, is utilized to train the YOLOv5 model. This set consists of images and their corresponding annotated bounding boxes.

*2) Training setup*: The YOLOv5 model is configured by incorporating the modified configuration file and the pre-processed training data. The configuration file contains parameters such as the number of classes, input image size, and network architecture. The pre-processed training data includes resized images, normalized pixel values, and annotated bounding boxes.

*3) Model initialization*: Before training begins, the YOLOv5 model is initialized with random weights. These initial weights serve as a starting point for the training process.

*4) Loss function and optimizer*: To train the YOLOv5 model for object detection, a suitable loss function is chosen. YOLOv5-specific loss functions like YOLOv5 Loss or GIoU Loss are commonly used. The loss function quantifies the discrepancy between predicted bounding boxes and the ground truth annotations. An optimizer, such as SGD or Adam, is employed to update the model's weights based on the computed loss.

*5) Batch size and epochs*: The training process involves feeding the training data to the YOLOv5 model in batches. The batch size determines the number of images processed before weight updates occur. Depending on available computational resources, typical batch sizes range from 8 to 32. The number of training epochs specifies how many iterations are performed over the entire training dataset. This value is chosen based on convergence and desired model performance.

*6) Forward and backward pass*: The training data is passed through the YOLOv5 model in batches during each training iteration. The model predicts bounding box coordinates, objectness scores, and class probabilities. The loss between the predicted values and the ground truth annotations is calculated. This loss is then used to update the model's weights through backpropagation, which adjusts the parameters to minimize the discrepancy between predictions and ground truth.

*7) Training monitoring*: The training process is monitored to assess the model's progress and performance. Metrics such as loss and accuracy are tracked to evaluate the model's convergence and generalization. Tools like TensorBoard can be utilized to visualize the training metrics and observe any trends or patterns over time. Logging the metrics at regular intervals allows for analysis and fine-tuning of the training process.

By following these steps, the YOLOv5 model is trained using the provided dataset, enabling it to learn to detect and classify fruits based on their grading criteria accurately.

*D. Model Validation*

During the validation process for the generated YOLOv5 model used in fruit grading and sorting, the following steps are involved:

*1) Validation set usage:* The 20% validation set is utilized to evaluate the performance of the trained YOLOv5 model. This set consists of images from the dataset that were not used during training.

*2) Model evaluation:* The trained YOLOv5 model is applied to the validation images, and predictions are made for the bounding box coordinates, objectness scores, and class probabilities. These predicted values are then compared with the ground truth annotations provided in the validation set.

*3) Calculation of evaluation metrics:* To assess the accuracy and generalization capabilities of the YOLOv5 model, evaluation metrics such as mean average precision (mAP) are calculated. The mAP measures the precision and recall of the detected objects across various confidence thresholds. Higher mAP scores indicate better detection accuracy.

*4) Hyperparameter tuning:* Based on the results obtained from the validation process, adjustments can be made to fine-tune hyperparameters or modify the training settings to improve the model's performance. This may involve changing parameters such as the learning rate, optimizer, and batch size or adjusting the number of training epochs.

The validation process helps in evaluating how well the YOLOv5 model generalizes to unseen data and provides insights into its overall performance. By assessing metrics like mAP, we can gauge the model's ability to detect and classify fruits for grading and sorting purposes accurately. Fine-tuning the hyperparameters based on validation results allows us to optimize the model's performance further and ensure its effectiveness in real-world scenarios.

## IV. RESULTS AND DISCUSSION

This section presents experimental results, performance evaluation of the YOLOv5 algorithm, performance result of training and performance result of validation.

*A. Experimental Results*

The generated YOLOv5 model for fruit grading has achieved accurate results, demonstrating its proficiency in accurately detecting, localizing, and classifying fruits. The model's architecture, optimized loss functions, and training process have contributed to its accuracy, as validated by metrics such as mean average precision (mAP). With the ability to precisely locate fruit bounding boxes and assign correct class or grade labels, the YOLOv5 model proves its effectiveness for automated fruit grading and sorting systems, offering a reliable and consistent quality assessment. Fig. 2 demonstrates some samples of our experimental results.

Fig. 2.   Sample of experimental results.

*B. Performance Evaluation of YOLOv5 Algorithm*

The graph comparing the mAP (mean average precision) of YOLO base models, such as YOLOv5, YOLOv6, YOLOv7, and YOLOv8, with the number of parameters plotted on the X-axis, reveals that YOLOv5 stands out as a smaller and more compact model compared to the others. Despite its smaller size, YOLOv5 still maintains competitive performance regarding mAP. Fig. 3 demonstrates the performance evaluation of the YOLOv5 algorithm in terms of the number of parameters.

As shown in Fig. 3, the fact that YOLOv5 has lower parameters while achieving comparable mAP scores indicates that it is designed to be a fast, accurate, and efficient model. The reduced parameter count means that YOLOv5 requires less computational resources, making it more lightweight and easier to deploy on various devices and platforms.

The design of YOLOv5 focuses on striking a balance between speed and accuracy, making it an excellent choice for a wide range of object detection applications. Its smaller size allows for faster inference times, enabling real-time or near-real-time object detection. The model's accuracy, as indicated by its competitive mAP scores, ensures reliable and precise object detection results.

Moreover, Fig. 4 illustrates the performance result of the YOLOv5 model in terms of latency. The model is designed to be fast and easy to use and implement, making it accessible to both researchers and practitioners. Its simplicity and effectiveness make YOLOv5 a popular choice for object detection tasks in various domains, including fruit grading and sorting.

Therefore, the YOLOv5 model's smaller size, lower parameter count, competitive mAP scores, and user-friendly design make it a fast, accurate, and easy-to-use option for a wide range of object detection applications. Its efficient performance and ease of deployment make it particularly suitable for tasks where real-time or near-real-time object detection is required, such as fruit grading and sorting.
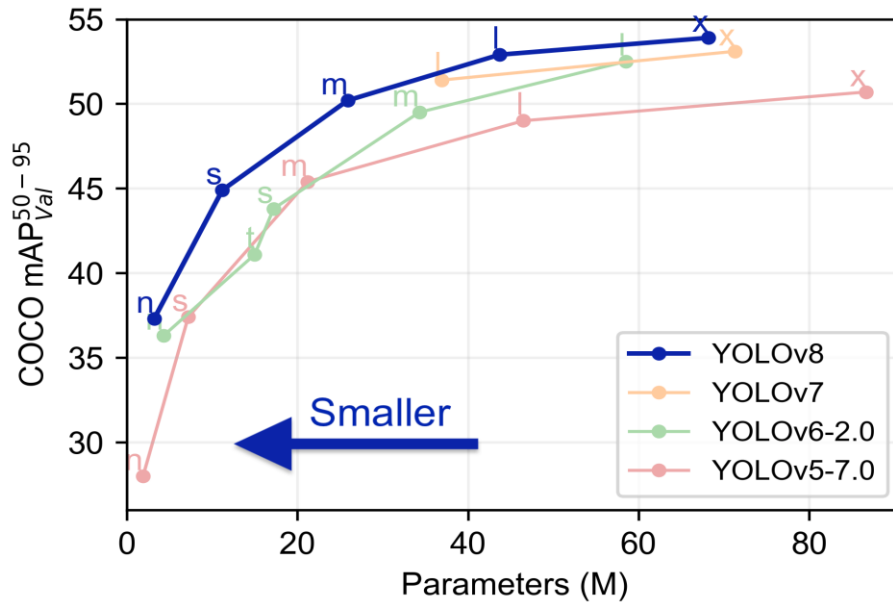
Fig. 3.    Performance Evaluation of  the YOLOv5 Algorithm in terms of the number of parameters  [23].
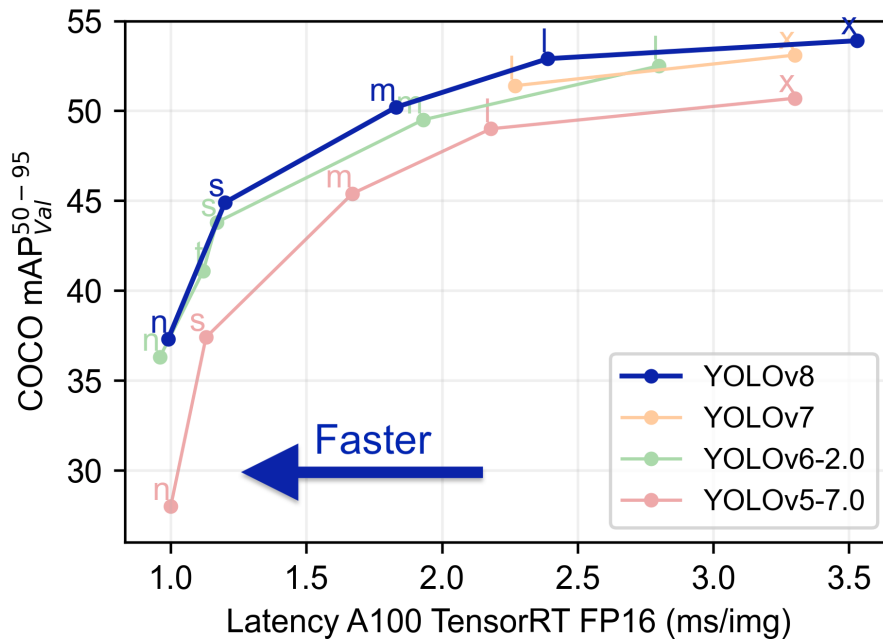


Fig. 4.    Performance result of the YOLOv5 model in terms of latency [23].

*C.  Performance Result of Training*

When training a YOLOv5 model for fruit grading, several graphs can be generated to monitor the training progress and assess the model's accuracy. The most commonly analyzed graphs include the train/box_loss, train/obj_loss, and train/cls_loss graphs. Fig. 5 shows the performance result of training.

As shown in Fig. 5, train/box_loss Graph: This graph represents the box loss over the course of training. The box loss measures the discrepancy between the predicted bounding box coordinates and the ground truth annotations. A lower box loss indicates that the model is accurately predicting the positions and sizes of the fruit bounding boxes. As the training progresses, we aim to see a decreasing trend in the box loss graph, which signifies that the model is improving its ability to locate the fruits precisely.
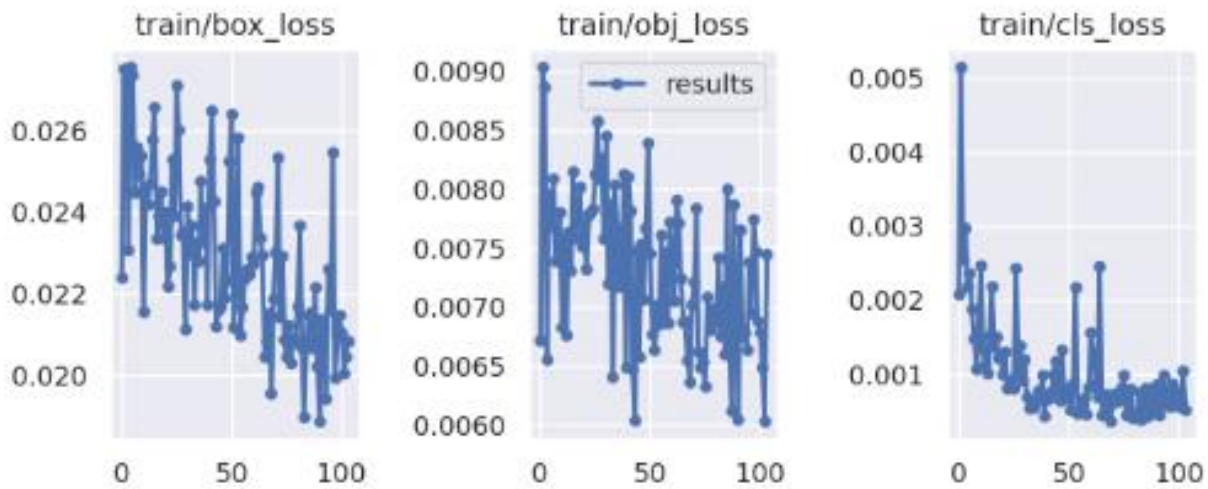
Fig. 5.   Performance result of training.

Train/obj_loss Graph: The obj_loss graph depicts the objectness loss throughout the training process. The objectness loss quantifies the difference between the predicted objectness scores (indicating the presence of an object) and the ground truth labels. As the model learns, it should minimize the obj_loss, indicating that it becomes more accurate in determining the presence or absence of fruits in the images. A decreasing obj_loss graph suggests that the model is becoming more proficient in identifying fruits accurately.

Train/cls_loss Graph: The cls_loss graph illustrates the classification loss during training. This loss measures the discrepancy between the predicted class probabilities and the ground truth labels. Fruit grading involves assigning the correct class or grade to each fruit. By monitoring the cls_loss graph, we can ensure that the model is learning to classify the fruits accurately. A decreasing cls_loss graph indicates that the model is improving its ability to assign the correct class probabilities to different fruit types or grades.

Achieving accuracy in training using these graphs involves monitoring their trends and making necessary adjustments. If the box_loss, obj_loss, or cls_loss values are not decreasing or stabilizing over time, it may indicate that the model needs further optimization. Possible steps to enhance accuracy include adjusting the learning rate, modifying the loss function, increasing the training dataset size, or fine-tuning the model architecture.

By closely monitoring these graphs and iteratively improving the model based on the insights gained from them, we can train a YOLOv5 model that accurately detects, localizes, and classifies fruits for grading purposes. The aim is to achieve decreasing losses over time, indicating the model's increasing accuracy and proficiency in fruit grading tasks.

### D. Performance Result of Validation

The validation graphs, including val/box_loss, val/obj_loss, and val/cls_loss, play a crucial role in achieving an accurate YOLOv5 model for fruit grading. These graphs provide valuable insights into the model's performance on unseen validation data and guide us in improving its accuracy. By analyzing these graphs, we can assess the model's ability to accurately localize fruits, determine their presence or absence, and classify them correctly. Fig. 6 displays the performance result of validation.
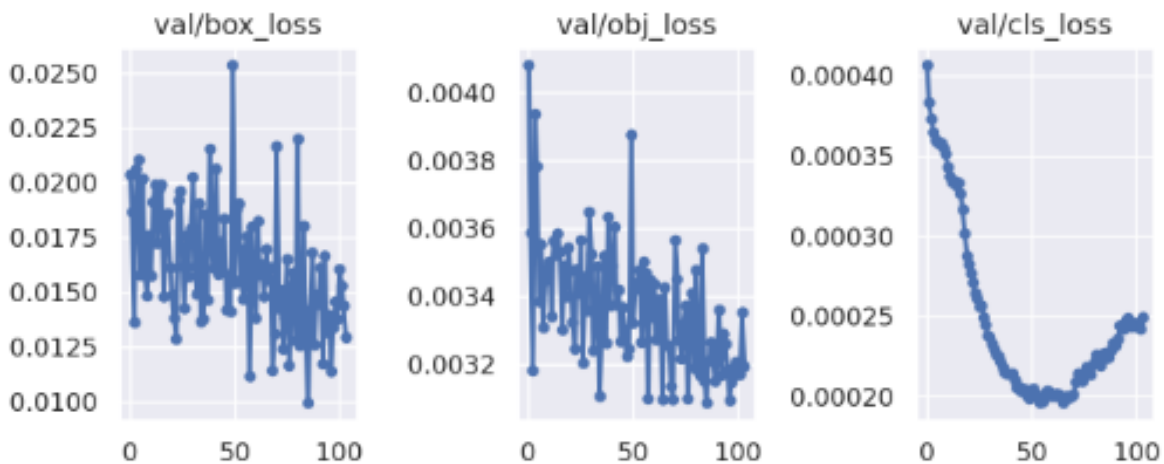


Fig. 6.   Performance result of validation.

As shown in Fig. 6, the val/box_loss graph helps us evaluate how well the model is localizing fruits by measuring the discrepancy between predicted bounding box coordinates and ground truth annotations. A decreasing trend in the val/box_loss graph indicates that the model is improving its accuracy in fruit localization.

The val/obj_loss graph allows us to assess the model's ability to detect fruits by comparing predicted objectness scores with ground truth labels. A decreasing trend in the val/obj_loss graph indicates that the model is becoming more accurate in determining the presence or absence of fruits in the validation images.

The val/cls_loss graph helps us evaluate the model's fruit grading performance by measuring the discrepancy between predicted class probabilities and ground truth labels. A decreasing trend in the val/cls_loss graph indicates that the model is improving its accuracy in assigning the correct class or grade to each fruit.

By monitoring these validation graphs and making necessary adjustments based on their trends, we can refine the YOLOv5 model for fruit grading, leading to enhanced accuracy in fruit localization, object detection, and classification. These insights help us optimize the model's performance and ensure its effectiveness in real-world fruit grading and sorting applications.

## V. CONCLUSION

This paper presents a novel solution to bridge the research gap in automated fruit grading in precise agriculture. This approach focuses on proposing a lightweight deep learning method utilizing YOLO (You Only Look Once) algorithms. To train a robust and efficient model, we utilize a custom dataset consisting of fruit images and conduct a rigorous training, validation, and testing process. The contributions lie in identifying the need for low computational cost and high accuracy rate requirements, introducing a lightweight deep learning-based method to overcome these limitations, and conducting extensive experimental and performance evaluations to validate the efficacy of the approach. Directions for future work can be considered to improve the computational efficiency of the automated fruit grading system. This can involve exploring techniques such as model compression, quantization, or optimization algorithms to reduce the computational cost without compromising accuracy. Investigating hardware acceleration techniques, such as utilizing specialized processors or GPUs, can also be explored to speed up the inference process.

Moreover, integrating multi-modal data sources, such as incorporating spectral or hyperspectral imaging, can provide additional valuable information for fruit grading. Future research can focus on developing fusion models that combine visual data with other modalities to enhance the accuracy and robustness of the fruit grading system. This can potentially improve the system's ability to handle various fruit types, different lighting conditions, and other environmental factors, leading to more precise and reliable grading results.

## REFERENCES

[1] I. Cisternas, I. Velásquez, A. Caro, and A. Rodríguez, "Systematic literature review of implementations of precision agriculture," Computers and Electronics in Agriculture, vol. 176, p. 105626, 2020.

[2] U. Shafi, R. Mumtaz, J. García-Nieto, S. A. Hassan, S. A. R. Zaidi, and N. Iqbal, "Precision agriculture techniques and practices: From considerations to applications," Sensors, vol. 19, no. 17, p. 3796, 2019.

[3] R. Akhter and S. A. Sofi, "Precision agriculture using IoT data analytics and machine learning," Journal of King Saud University-Computer and Information Sciences, vol. 34, no. 8, pp. 5602-5618, 2022.

[4] H. Tian, T. Wang, Y. Liu, X. Qiao, and Y. Li, "Computer vision technology in agricultural automation—A review," Information Processing in Agriculture, vol. 7, no. 1, pp. 1-19, 2020.

[5] R. Gai, N. Chen, and H. Yuan, "A detection algorithm for cherry fruits based on the improved YOLO-v4 model," Neural Computing and Applications, vol. 35, no. 19, pp. 13895-13906, 2023.

[6] M. C. Ang, A. Aghamohammadi, K. W. Ng, E. Sundararajan, M. Mogharrebi, and T. L. Lim, "Multi-core frameworks investigation on a real-time object tracking application," Journal of Theoretical & Applied Information Technology, vol. 70, no. 1, 2014.

[7] H. H. Kuo, D. S. Barik, J. Y. Zhou, Y. K. Hong, J. J. Yan, and M. H. Yen, "Design and Implementation of AI aided Fruit Grading Using Image Recognition," in 2022 IEEE/ACIS 23rd International Conference on Software Engineering, Artificial Intelligence, Networking and Parallel/Distributed Computing (SNPD), 2022: IEEE, pp. 194-199.

[8] Q. An, K. Wang, Z. Li, C. Song, X. Tang, and J. Song, "Real-Time Monitoring Method of Strawberry Fruit Growth State Based on YOLO Improved Model," IEEE Access, vol. 10, pp. 124363-124372, 2022.

[9] M. Ang, E. Sundararajan, K. Ng, A. Aghamohammadi, and T. Lim, "Investigation of Threading Building Blocks Framework on Real Time Visual Object Tracking Algorithm," Applied Mechanics and Materials, vol. 666, pp. 240-244, 2014.

[10] N. Kumari, R. K. Dwivedi, A. K. Bhatt, and R. Belwal, "Automated fruit grading using optimal feature selection and hybrid classification by self-adaptive chicken swarm optimization: grading of mango," Neural computing and applications, pp. 1-22, 2022.

[11] V. Meshram, K. Patil, V. Meshram, D. Hanchate, and S. Ramkteke, "Machine learning in agriculture domain: A state-of-art survey," Artificial Intelligence in the Life Sciences, vol. 1, p. 100010, 2021.

[12] N. Mamdouh and A. Khattab, "YOLO-based deep learning framework for olive fruit fly detection and counting," IEEE Access, vol. 9, pp. 84252-84262, 2021.

[13] A. Albanese, M. Nardello, and D. Brunelli, "Automated pest detection with DNN on the edge for precision agriculture," IEEE Journal on Emerging and Selected Topics in Circuits and Systems, vol. 11, no. 3, pp. 458-467, 2021.

[14] S. A. Magalhães et al., "Evaluating the single-shot multibox detector and YOLO deep learning models for the detection of tomatoes in a greenhouse," Sensors, vol. 21, no. 10, p. 3569, 2021.

[15] Y. Zhang, W. Zhang, J. Yu, L. He, J. Chen, and Y. He, "Complete and accurate holly fruits counting using YOLOX object detection," Computers and Electronics in Agriculture, vol. 198, p. 107062, 2022.

[16] M. H. Saleem, J. Potgieter, and K. M. Arif, "Automation in agriculture by machine and deep learning techniques: A review of recent developments," Precision Agriculture, vol. 22, pp. 2053-2091, 2021.

[17] N. Mamat, M. F. Othman, R. Abdulghafor, A. A. Alwan, and Y. Gulzar, "Enhancing image annotation technique of fruit classification using a deep learning approach," Sustainability, vol. 15, no. 2, p. 901, 2023.

[18] M. M. Raikar, S. Meena, C. Kuchanur, S. Girraddi, and P. Benagi, "Classification and Grading of Okra-ladies finger using Deep Learning," Procedia computer science, vol. 171, pp. 2380-2389, 2020.

[19] N. Ismail and O. A. Malik, "Real-time visual inspection system for grading fruits using computer vision and deep learning techniques," Information Processing in Agriculture, vol. 9, no. 1, pp. 24-37, 2022.

[20] P. U. Patil, S. B. Lande, V. J. Nagalkar, S. B. Nikam, and G. Wakchaure, "Grading and sorting technique of dragon fruits using machine learning algorithms," Journal of Agriculture and Food Research, vol. 4, p. 100118, 2021.

[21] S. K. Chakraborty et al., "Development of an optimally designed real-time automatic citrus fruit grading–sorting machine leveraging computer vision-based adaptive deep learning model," Engineering Applications of Artificial Intelligence, vol. 120, p. 105826, 2023.

[22] I. Katsamenis et al., "TraCon: A novel dataset for real-time traffic cones detection using deep learning," in Novel & Intelligent Digital Systems Conferences, 2022: Springer, pp. 382-391.

[23] G. Jocher. "YOLOv5 by Ultralytics." https://github.com/ultralytics/yolov5 (accessed.

# Image Stitching Method and Implementation for Immersive 3D Ink Element Animation Production

Chen Yang[1*], Siti SalmiJamali[2], Adzira Husain[3], Nianyou Zhu[4], Jian Wen[5]

School of Fashion Media, Jiangxi Institute of Fashion Technology, Nanchang, 330201, China[1]

School of Creative Industry Management and Performing Arts-College of Arts and Sciences, Universiti Utara Malaysia, 06010, Sintok, Kedah, Malaysia[1, 2, 3]

School of Architecture and Art Design, Jiangxi Technical College of Manufacturing, Nanchang, 330095, China[4]

Business School, Jiangxi Institute of Fashion Technology, Nanchang, 330201, China[5]

*Abstract*—As the growth of immersive 3D animation, its application in ink element animation is constantly updating and advancing. However, the current immersive 3D ink element animation production also has the problem of lack of innovation and repeated development, so the research innovatively designs and develops the image stitching method for immersive 3D ink element animation production. The method is designed through stereo matching algorithm and scale-invariant feature transform algorithm, and the stereo matching algorithm is optimized with the weighted median filtering method based on the guide map. In addition, the study also designs the specific implementation of this method from different functional modules. The experimental results show that on four different datasets, the error percentages of the optimized stereo matching algorithm in non-occluded areas are 0.3885%, 0.4743%, 1.6848%, and 1.34%, respectively. The error percentages of all areas are 0.8316%, 0.8253%, 4.3235%, and 4.1760%, respectively. The research and design of image stitching methods can be applied in other fields and has good practical significance.

*Keywords*—*Immersive; 3D; ink element animation; image stitching; stereo matching algorithm*

## I. INTRODUCTION

As the advancement of immersive 3D animation, it has gradually become a popular form of artistic expression in animation [1]. Immersive 3D animation technology is developed on the basis of computer vision technology and image technology, and can complete its own construction through fixed steps [2]. Stereoscopic 3D animation can generate highly realistic 3D animation images by simulating the human visual system. With the development of 3D technology, the design and application of ink element animation (IEA) in 3D animation are also constantly deepening [3-4]. However, at present, the quality of immersive 3D ink element animation production enterprises is uneven, and the content produced by most enterprises is also very superficial. And this also leads to a lack of deeper thinking and spirit in the current immersive 3D ink element animation, a lack of innovation, and the problem of repeated development [5]. The current solution to the problem of missing content is to transform the existing classic 3D ink element animation into immersive 3D ink element animation, which requires the use of image stitching algorithms [6]. At present, research on image stitching algorithms mainly focuses on the stitching of monocular images, with less involvement in the stitching of

binocular images. Due to the visual differences between left and right eye images, it is not appropriate to directly use monocular image stitching to process binocular images, which can affect consumers' viewing experience [7]. Based on these issues, the study innovatively designed and developed an image stitching method for immersive 3D ink element animation production, starting from the horizontal parallax dependence of stereoscopic perception. The method was designed using stereo matching algorithms and scale invariant feature conversion algorithms, and the specific implementation of the method was designed from different functional modules. The research aims to design image stitching methods for immersive 3D ink element animation production through stereo matching algorithms and scale invariant feature transformation algorithms, solve the problem of disparity, maintain the three-dimensional sense of animation, and improve the viewing experience of consumers. There are two innovative points in the research, one is the combination of stereo matching algorithm and scale invariant feature transformation algorithm, and the other is the use of weighted median filtering method to improve the stereo matching algorithm. The research is divided into four parts. The first part is a literature review, mainly involving the literature review of image stitching methods for immersive 3D ink element animation production. The second part is the specific design of image stitching methods, including image stitching algorithm design, image stitching architecture design, and functional model implementation design. The third part is the analysis of the results of the image stitching method, mainly including the performance verification of the algorithm designed by the research institute and the overall effect analysis of the image stitching method. The fourth part is the conclusion of the study, mainly summarizing and elaborating on the results of the image stitching method designed by the research institute.

## II. RELATED WORKS

With the growth of immersive 3D animation technology, its own application fields are constantly expanding, and research on IS methods for immersive 3D IEA production is gradually enriching. To explore the animation of virtual medical systems, researchers such as Li designed a virtual medical system based on reality technology and 3D animation modeling. The experimental findings denoted that the calculated results under the implicit method did not increase

with the increase of the difference, and had good stability when obtaining larger values [8]. Sandoub and other experts proposed a low light level image enhancement algorithm based on fusion to avoid halo artifacts and color distortion issues when enhancing images. This algorithm estimated the illumination of low light images through the maximum color channel, and used thinning methods to improve the sharpness of the initial enhanced image. The research outcomes indicated that the proposed method was significantly superior to existing methods and reduced the issues of halo artifacts and color distortion [9]. Hosseinzadeh and other scholars proposed a new method for image centralization and pose estimation to study the creation of stitched images inside pipelines. This method would inspect and concentrate the captured video, and then generated a stitching image of the interior of the pipeline. The research findings expressed that this method had good results in IS inside pipelines [10]. Damghani and other researchers proposed an adaptive method to reduce the distortion caused by embedding information in the transformation space. This method was based on the interaction between the changes made when embedding the algorithm. The research results indicated that this method was more efficient than the most advanced methods in the field [11]. Ro and other experts put forward an in situ analysis method of mineralogy based on handheld microscope to conduct in situ analysis of mineralogy. This method solved the small observation range of microscopes through IS. The experimental outcomes denoted that this method was very effective in real-time mineralogy analysis [12].

Chen and other scholars proposed a method to convert 3D motion graphics to stereoscopic display to realize the use of stereoscopic video on mobile platforms. This method was mainly developed on the basis of animation software and output synthetic images that match the stereoscopic display. The research findings expressed that compared to traditional methods, this method had better results and faster speed in image generation [13]. Nie and other researchers proposed an IS learning framework to avoid the issue of unavailability of traditional IS methods. The framework estimated the homography through the multi-scale depth homography model, and learned the deformation rules of IS through the edge preserving deformation module. The experimental outcomes expressed that the framework had good generalization ability and was significantly superior to existing methods [14]. Dai and other experts proposed an end-to-end deep learning framework to solve the problem of artifacts when creating Panorama. This framework considered the synthesis stage in IS as a problem of image mixing and used perceptual edges to guide the network. The experimental results indicated that the framework could generate useful results in less time and had good performance [15]. Zhao and other scholars proposed an IS method based on depth homography estimation to solve the low IS accuracy. This method involved resolution and feature maps and a loss function for stitching. The experimental findings expressed that this method had good performance in quantitative evaluation and visual stitching effects [16]. Luo and other researchers proposed an IS method with constraint on the position relationship between feature points and lines to eliminate parallax. This method reduced the computation of feature matching by quickly detecting overlapping areas, and

guided mesh deformation through local mesh models [17].

In summary, there is currently a wealth of research on IS methods for immersive 3D IEA production both domestically and internationally, and the methods used are also diverse. However, these studies also have certain problems, such as the lack of innovation in immersive 3D animation content, and repeated development in one direction. Therefore, the research innovatively proposes an IS method for immersive 3D IEA, constructs the method through SM algorithm and SIFT algorithm, and designs the specific implementation of the method.

## III. CONSTRUCTION OF IMAGE SPLICING METHOD AND DESIGN OF FUNCTIONAL MODEL IMPLEMENTATION METHOD FOR 2D IEA PRODUCTION

To construct an IS method for immersive 3D IEA, SM algorithm and SIFT algorithm are applied in the design of its functional modules. In addition, to better utilize the role of SM algorithms, a weighted median filtering method based on directional maps is used to optimize it. To design the specific implementation of the IS method functional module, the development language, library functions, and specific implementation steps of the module are studied and explained.

### A. Design of IS Methods for Immersive 3D IEA Production

3D animation is a form of animation that includes computer graphics technology and is not limited by time and space conditions. 3D IEA is mainly produced through computer 3D software, which involves model building and light and shadow settings [18-19]. The production of 3D IEA should be based on its own spatial construction characteristics to achieve spatial transformation. The spatial construction characteristics of 3D IEA are shown in Fig. 1.
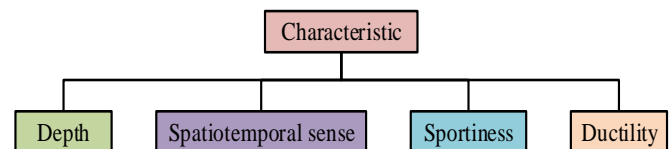


Fig. 1.    The spatial construction characteristics of 3D IEA.

As shown in Fig. 1, the spatial construction characteristics of 3D IEA mainly include four points, namely stereo sense, spatiotemporal sense, motion sense, and extensibility. The stitching of immersive 3D IEA is mainly divided into seven steps. The first step is to input the image, the second step is to preprocess the data, and the third step is to register the image. The fourth step is to establish the transformation model, the fifth step is to carry out unified coordinate transformation, the sixth step is to fuse the images, and the seventh step is to obtain panoramic images. Among them, image registration and fusion are the core steps. SM algorithms can be divided into global and local SM algorithms, while the Semi Global Matching (SGM) algorithm belongs to the global algorithm [20]. The pixel level cost and smoothing constraints of the SGM algorithm are shown in Eq. (1).

$$E(D) = \sum_p \left( C(p, D_p) + \sum_{q \in N_p} P_1 T\left(\left|D_p - D_q\right| = 1\right) + \sum_{q \in N_p} P_2 T\left(\left|D_p - D_q\right| > 1\right) \right) \quad (1)$$

In Eq. (1), $D$ denotes the disparity variable; $q$ and $p$ express pixels; $P_1$ means the penalty factor; $P_2$ indicates the constant penalty factor with larger values; $C$ represents the matching cost of pixels; $Np$ refers to adjacent pixels of pixel $p$; $T$ denotes the judgment value. The calculation of $P_2$ is shown in Eq. (2).

$$P_2 = \frac{P_2}{\left| I_{bp} - I_{bq} \right|} \tag{2}$$

In Eq. (2), $I_b$ indicates the reference map. When performing cost aggregation, the SGM global energy function is shown in Eq. (3).

$$E(D) = \sum_p C(p, D_p) + \sum_{q \in Np} P_1 T \left[ \left| D_p - D_q \right| = 1 \right] + \sum_{q \in Np} P_2 T \left[ \left| D_p - D_q \right| > 1 \right] \tag{3}$$

The sum of matching costs for pixels in disparity $D$ is achieved through term $\sum C(p, D_p)$. The SGM algorithm can avoid the approximate solution of equation conversion and solve one-dimensional problems in eight directions, as shown in Eq. (4).

$$L_r(p, d) = C(p, d) + \min(L_r(p - r, d)),$$
$$L_r(p - r, d - 1) + P_1$$
$$L_r(p - r, d + 1) + P_1$$
$$\min(L_r(p - r, i) + P_2) - \min L_r(p - r, d + 1) k \tag{4}$$

In Eq. (4), $r$ stands for a direction pointing towards the current pixel $p$; $d$ expresses the value of parallax; $i$ and $k$ represent the pixel grayscale value.

### B. IS Architecture Design for Immersive 3D IEA Production

There are three common ways to make 3D animated films, of which the first involves computer graphics technology. The second type will use parallel cameras for production, and the third type will use relevant algorithms and software [21]. To make the immersive 3D IEA better, the research uses a method that combines computer graphics technology and live shooting technology. The overall architecture of the IS system for immersive 3D IEA production is shown in Fig. 2.

As shown in Fig. 2, the IS system for immersive 3D IEA production is mainly divided into three modules, namely the 3D image source on-demand acquisition module, the ensuring parallax comfortable stitching module, and the display module. The on-demand acquisition module for stereoscopic image sources involves calculating the viewing comfort range, determining the optimal shooting position, and promoting the development of animation plots. The module for ensuring comfortable disparity stitching mainly involves depth IS, image SM, weighted median filtering, and stitching. The display module mainly includes parallax optimized line chart and panoramic effect display. When obtaining stereoscopic image sources on demand, the positioning of virtual stereoscopic cameras is mainly achieved based on the input needs of the viewer. In addition, the manipulation of scene nodes can be completed through Maya software. After the generation of stereo images, stereo perception correspondence is required, and the corresponding of stereo perception is shown in Fig. 3.
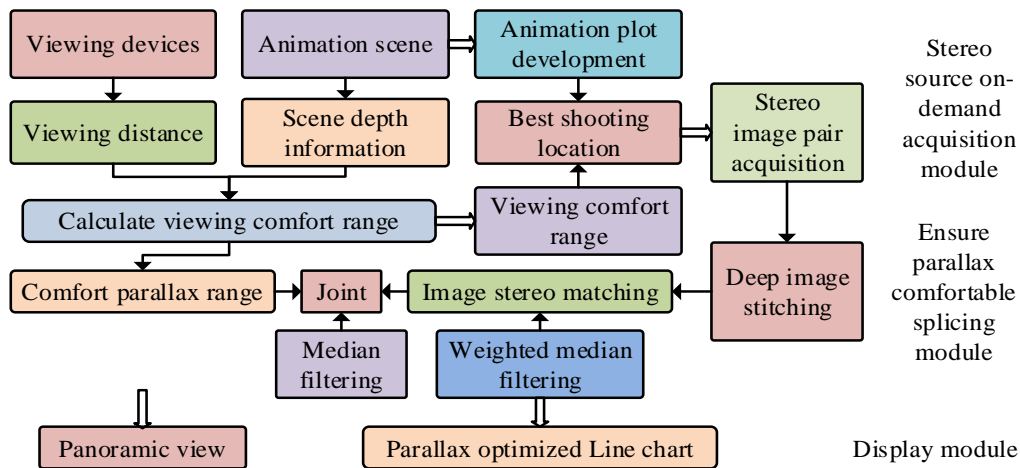


Fig. 2. The overall architecture of IS system.
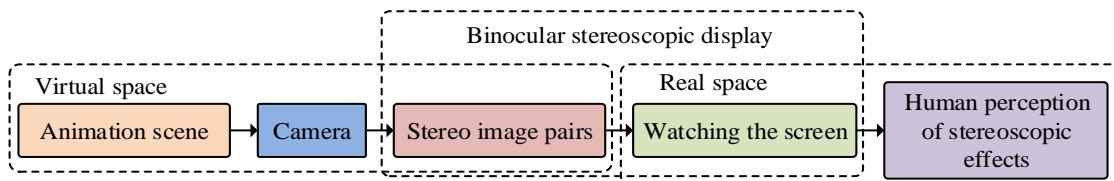


Fig. 3. The corresponding process of stereoscopic perception.

As shown in Fig. 3, the corresponding process of stereo perception is divided into three main parts: virtual space, binocular stereo display, and real space. Virtual space includes animated scenes and cameras, binocular stereo display involves stereo image pairs and viewing screens, and real space mainly includes human eye perception of stereo effects. Immersive 3D IS uses the SIFT (SIFT) algorithm, which can observe and analyze local features in images and videos. The SIFT algorithm is mainly divided into four steps. The first step is to detect the extreme values in the scale space, the second step is to locate the key points, the third step is to determine the method, and the fourth step is to describe the key points. To provide better IS functionality, the study used random sample consistency (RANSAC) algorithm and fast library for approximate nearest neighbors (FLANN) algorithm based on tree structure to optimize the SIFT algorithm. The optimization of disparity post-processing in SM algorithms is mainly achieved through the weighted median filtering (WMF) method based on directional maps [22]. This method is mainly divided into three steps. The first step is left and right consistency detection, the second step is filling in the disparity value of singular points, and the third step is smoothing the disparity value of singular points. When the matching information is insufficient, the expression of left and right consistency detection is shown in Eq. (5).

$$D_L(x,y) = D_R(x - D_L(x,y), y) \tag{5}$$

In Eq. (5), $D_L$ denotes the left disparity map of the left eye image pair; $D_R$ means the right disparity map of the right eye image pair; $(x,y)$ expresses the coordinates of the interest points based on the left eye image. When the disparity value of the point in the left eye image exceeds the boundary in the right eye image, the expression of left and right consistency detection is shown in Eq. (6).

$$x - D_L(x,y) \geq 0 \tag{6}$$

To preserve the high-frequency edges of the image, the WMF method is optimized. The weight calculation involved in optimization is shown in Eq. (7).

$$W_{\partial,j}^{bf} = \frac{1}{K_\partial} e^{\left(\frac{|\partial - j|^2}{\sigma_s^2}\right)} e^{\left(\frac{|I_\partial - I_j|^2}{\sigma_c^2}\right)} \tag{7}$$

In Eq. (7), $\partial$ and $j$ denote the coordinates of two points in the guidance map; $\sigma_c$ and $\sigma_s$ indicate constants; $K_\partial$ is used to control the weight size; $bf$ means the balance calculation value when the feature is $f$. The stereo display Comfort zone is $[D_{min}, D_{max}]$, and its calculation is shown in Eq. (8).

$$\begin{cases} D_{min}(v_d) = \frac{p_d}{2} \cot(\arctan \frac{p_d}{2v_d} + \frac{|\delta\theta|}{2}) \\ D_{max}(v_d) = \frac{p_d}{2} \cot(\arctan \frac{p_d}{2v_d} - \frac{|\delta\theta|}{2}) \end{cases} \tag{8}$$

In Eq. (8), $p_d$ means the distance between the binocular pupils; $v_d$ denotes the distance from the viewer to the screen; $\delta\theta$ expresses the difference between the convergence angle and the adjustment angle. The calculation of parallax at a certain point in the scene is shown in Eq. (9).

$$d = I_s \cdot f \left(\frac{1}{Z_p} - \frac{1}{D}\right) \tag{9}$$

In Eq. (9), $I_s$ expresses the distance between the axes of the cameras; $f$ means the focal length of the stereoscopic camera; $Z_p$ refers to the distance from the zero parallax plane to the camera plane. The mapping relationship between the depth of the scene and the disparity at a certain point in the scene is shown in Eq. (10).

$$p(D) = I_s \cdot \left(1 - \frac{Z_P}{D}\right) \tag{10}$$

By substituting Eq. (8) into Eq. (10), the mapping relationship between parallax and viewing distance can be established, as shown in Eq. (11).

$$\begin{cases} p_{min}(v_d) = p_d \cdot \left(1 - \frac{2v_d}{p_d \cot\left(\tan^{-1}\frac{p_d}{2v_d} + \frac{|\delta\theta|}{2}\right)}\right) \\ p_{max}(v_d) = p_d \cdot \left(1 - \frac{2v_d}{p_d \cot\left(\tan^{-1}\frac{p_d}{2v_d} - \frac{|\delta\theta|}{2}\right)}\right) \end{cases} \tag{11}$$

If $P_P$ is the parallax of a point in virtual space, its expression derived from the off axis model is shown in Eq. (12).

$$P_P = \left(1 - \frac{zp}{Z}\right) S \tag{12}$$

In Eq. (12), $zp$ means zero parallax; $S$ stands for the distance between the left and right eye cameras; $Z$ refers to the distance between the points in the scene and the stereo camera. If the perspective of the central camera is $\alpha$, the width of the projection plane is shown in Eq. (13).

$$W_p = 2 * zp * \tan \frac{\alpha}{2} \tag{13}$$

In Eq. (13), $W_p$ is the virtual unit of length. The expression of parallax in real space is shown in equation (14).

$$P_r = \frac{W_r}{W_P} P_p$$
(14)

At this point, if the pixel spacing is $P_p$, the final disparity is shown in Eq. (15).

$$P = P_r * b$$
(15)

### C. Design of Functional Model Implementation Methods for Immersive 3D IEA Production

To implement the functional modules of the IS method in detail, the study presents 3D IEA scenes on the basis of Maya software. During the preparation phase, the development language and library functions are set up. The Maya MEL language, which is the built-in scripting language of Maya software, is selected for development language research. The image library research selects OpenCV image library, which is powerful and has a modular structure. The functions of OpenCV can be divided into various types based on different purposes, such as video processing and graphical user interface functions. The implementation of IS method for immersive 3D IEA production is shown in Fig. 4.

In Fig. 4, the first step of the implementation of the IS method is to generate 3D image pairs, and the second step is to stitching Panorama. The third step is to generate the trget and reference Panoramas on the basis of Panorama staitching, and the fourth step is to calculate the panorama parallax. The fifth step is to optimize the seam of the current Panorama by combining the calculated panorama parallax map and the comfortable parallax range. The realization of the system function can be divided into five functional modules, namely, stereo image pair on-demand acquisition module, immersive 3D IS module, comfort zone calculation module, SM module and seam disparity optimization module. The implementation of different modules is shown in Fig. 5.

As shown in Fig. 5, the implementation of the on-demand acquisition module for stereo images mainly involves determining the position of virtual stereo cameras, which involves two methods. One is to customize the camera position by professionals, and the other is to use MEL scripting language. In addition, the rendering part is also implemented using MEL scripts. The immersive 3D IS module can achieve the acquisition of data such as the coordinates of the seam and the panoramic images of the left and right eyes through Panorama stitching of depth image pairs. In addition, the RANSAC algorithm is introduced into the findHomegraph function and used to solve the homography matrix of the image matrix. The comfort zone calculation module is mainly realized by calculating the user's viewing distance, pupil distance and other data, and the final output of the module is the range value of the comfort zone. The SM module calculates the disparity map of panoramic stereo images through the optimized SGM algorithm. The flowchart of disparity optimization at the seam is shown in Fig. 6.

In Fig. 6, the first step in optimizing the disparity at the seam is to input data into the panoramic disparity map, which mainly includes the comfortable disparity range, seam coordinate positioning, and viewing distance. The second step is to input the left Panorama into the panorama parallax map, and the panorama parallax map will return to the right Panorama based on the input data. The third step is to output the panoramic disparity map data and optimize the disparity at the seam.
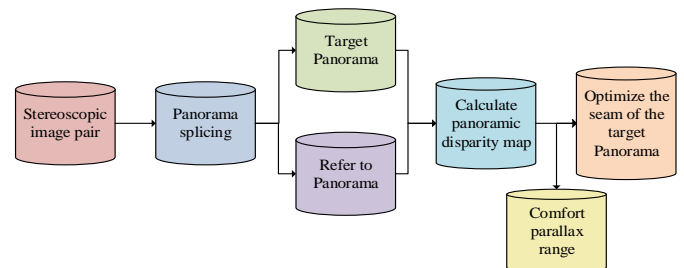


Fig. 4. Implementation of IS method.
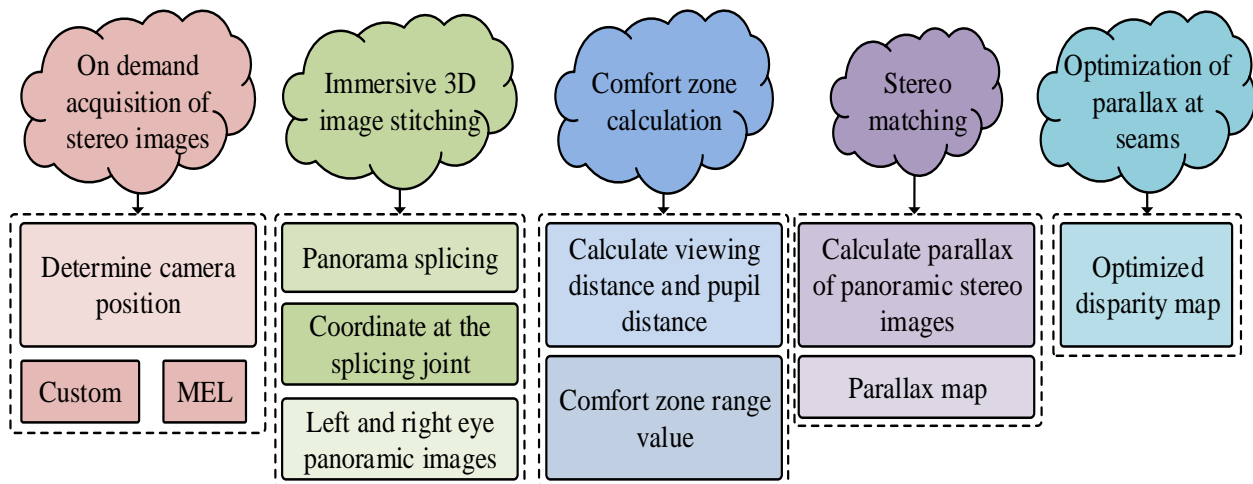


Fig. 5. Implementation of different modules.
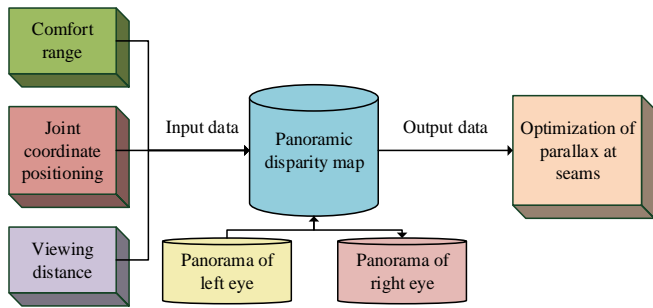
Fig. 6.    Flowchart for optimizing disparity at seams.

## IV.    RESULT ANALYSIS OF IS METHODS FOR IMMERSIVE 3D IEA PRODUCTION

To analyze the results of the IS method for immersive 3D IEA production, the functional module performance and overall performance of the IS method were studied. Among them, the performance analysis of functional modules was mainly achieved by comparing F1 values and image generation error rates under different datasets. The overall performance of IS methods was mainly analyzed through runtime and rendering effects.

### A. *Functional Module Performance Analysis of IS Methods for 3D IEA Production*

The performance testing and analysis of SM models were mainly achieved through algorithm comparison, and the selected comparison algorithms include the sum of squared differences (SSD) algorithm and the sum of absolute differences (SAD) algorithm. Four standards Middlebury stereo image datasets were selected, namely the Tsukuba, Venus, Teddy and Cones6 datasets. The comparison indicators included F1 value and error rate of image generation. The comparison of F1 values between different algorithms is shown in Fig. 7.

From Fig. 7 (a), on the Tsukuba dataset, the max, mini and average F1 value of the SGM algorithm were 0.996, 0.982 and 0.9904, respectively. The max, mini and average F1 value of the SSD algorithm were 0.885, 0.871 and 0.8794, respectively. The max, mini and average F1 value of the SAD algorithm were 0.874, 0.86 and 0.8684, respectively. From Fig. 7 (b), on

the Venus dataset, the max, mini and average F1 value of the SGM algorithm were 0.996, 0.981 and 0.9902, respectively. The max, mini and average F1 value of the SSD algorithm were 0.895, 0.88 and 0.8892. The max, mini and average F1 value of the SAD algorithm were 0.891, 0.876 and 0.8852. The performance of SGM algorithm was significantly better than the other two algorithms. To analyze the performance of the optimized SGM algorithm, the study selected SGM algorithms optimized using other filtering methods for comparison, including box filtering (Box), guided filtering (Guided), and bilateral filtering (BF). The comparison of matching error percentages for different SGM algorithms under the Tsukuba and Venus datasets is shown in Fig. 8.

From Fig. 8 (a), on the Tsukuba dataset, the error percentage of the SGM, SGM+Box, SGM+Box, SGM+BF and SGM+WMF algorithms in non-occluded areas were 3.3862%, 3.2254%, 3.0173%, 2.1268% and 0.3885%, respectively. On the Venus dataset, the error percentage of non-occluded areas in the five algorithms were 0.7217%, 0.7356%, 0.2329%, 0.5478% and 0.4743%, respectively. As shown in Fig. 8 (b), the error percentage of all regions of the five algorithms on the Tsukuba dataset were 5.9688%, 4.2336%, 3.7276%, 3.2244% and 0.8316%, respectively. On the Venus dataset, the error percentages for all regions of the five algorithms were 0.9946%, 0.8234%, 0.4562%, 0.6602%, and 0.8253%, respectively. The comparison of matching error percentages for different SGM algorithms under the Teddy and Cones6 datasets is shown in Fig. 9.

From Fig. 9 (a), on the Teddy dataset, the error percentage of non-occluded areas in the SGM, SGM+Box, SGM+Guided, SGM+BF and SGM+WMF algorithms were 2.1155%, 1.9232%, 3.2346%, 1.8020% and 1.6848%, respectively. On the Cones6 dataset, the error percentages for all regions of the five algorithms were 1.9993%, 1.6732%, 2.3449%, 1.3467%, and 1.34%, respectively. From Fig. 9 (b), on the Teddy dataset, the error percentage of all regions of the five algorithms were 5.0838%, 5.1033%, 4.8143%, 4.9133% and 4.3235%, respectively. On the Cones6 dataset, the error percentages for all regions of the five algorithms were 5.9187%, 5.8999%, 5.2333%, 4.6776%, and 4.1760%, respectively.
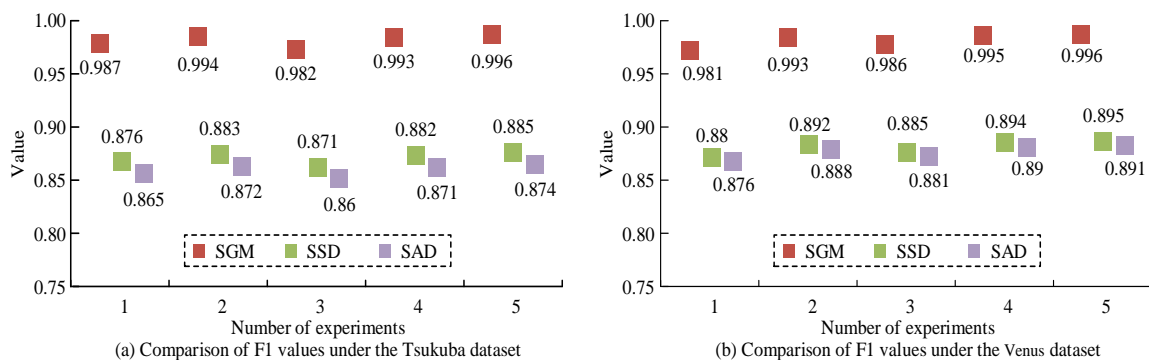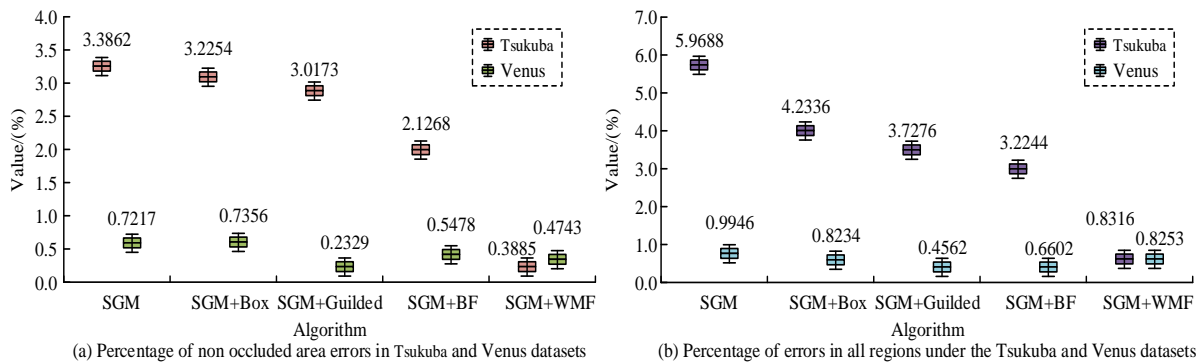


(a) Comparison of F1 values under the Tsukuba dataset



(b) Comparison of F1 values under the Venus dataset

Fig. 7.    Comparison of F1 values between different algorithms.

(a) Percentage of non occluded area errors in Tsukuba and Venus datasets

(b) Percentage of errors in all regions under the Tsukuba and Venus datasets

Fig. 8. Comparison of matching error percentages between different SGM algorithms on the Tsukuba and Venus datasets.



(a) Percentage of non occluded area errors in Teddy and Cones6 datasets

(b) Percentage of errors in all regions under the Teddy and Cones6 datasets
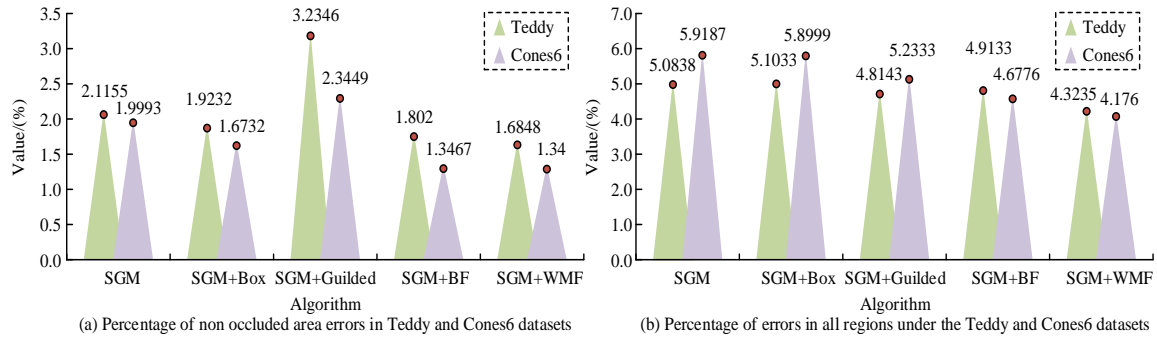
Fig. 9. Comparison of matching error percentages between different SGM algorithms on the Teddy and Cones6 datasets.

## B. Overall Effect Analysis of IS Methods for 3D IEA Production

To analyze the overall effect of IS methods for 3D IEA production; the running time of different SGM algorithms was compared. The image rendering results of the 3D IEA production IS method was mainly evaluated by observer scoring. In addition, the overall performance of the IS method was analyzed through the smoothness and restoration of the image. The comparison of the runtime of different SGM algorithms on different datasets is shown in Fig. 10.

From Fig. 10 (a), on the Tsukuba and Venus datasets, the
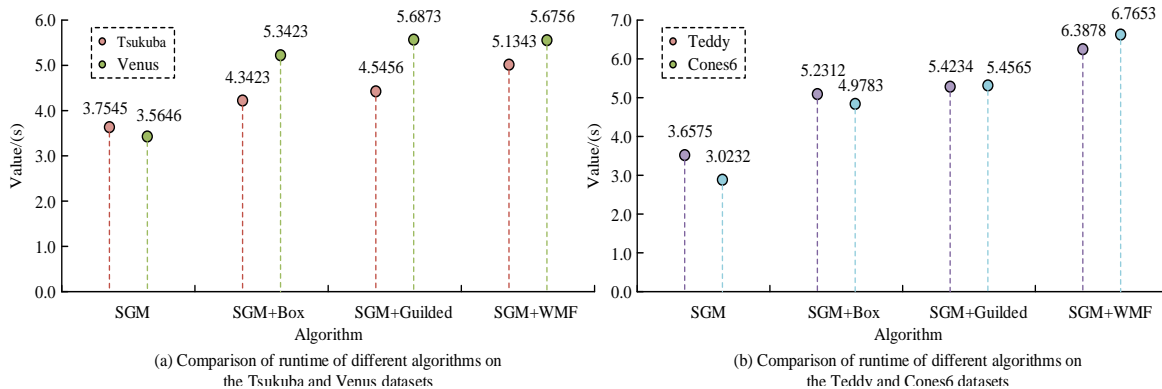
running time of the SGM, SGM+Box, SGM+Guided and SGM+WMF algorithms were 3.7446s and 3.5657s, 4.3434s and 5.3434s, 4.5467s and 5.6884s, 5.1354s and 5.6767s, respectively. From Fig. 10 (b), on the Teddy and Cones6 datasets, the running time of the SGM, SGM+Box, SGM+Guided and SGM+WMF algorithms were 3.6586s and 3.0243s, 5.2323s and 4.9794s, 5.4245s and 5.4576s, 6.3889s and 6.7664s, respectively. In summary, although the SGM+WMF algorithm had no significant advantage in runtime, it had no impact on the overall performance of the method. The image rendering results of the 3D IEA production IS methods are shown in Fig. 11.



(a) Comparison of runtime of different algorithms on the Tsukuba and Venus datasets

(b) Comparison of runtime of different algorithms on the Teddy and Cones6 datasets

Fig. 10. Comparison of runtime of different SGM algorithms on different datasets.

(a) The rendering score of animation 1 for 5 consecutive frames of animation          (b) The rendering score of animation 2 for 5 consecutive frames of animation

Fig. 11. Image rendering results for different animations.



(a) Smoothness comparison of 5 consecutive frames of animation

(b) Comparison of Restorability for 5 consecutive frames of animation
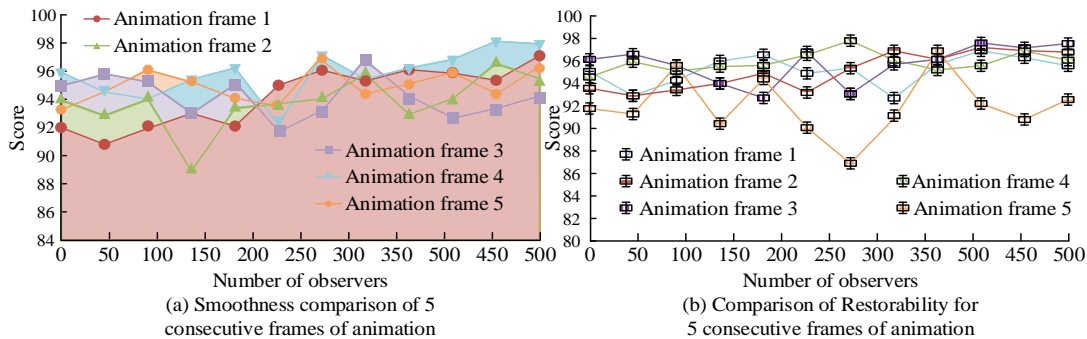
Fig. 12. Image smoothness and restoration.

From Fig. 11 (a), in the first ink painting animation, the max and mini rendering score of the first frame image were 98.5 and 81.3, respectively. The max and mini rendering scores for the second frame were 98.9 and 88.7, respectively. The max and mini rendering scores for the third frame were 99.5 and 97.3, respectively. The max and mini score for the fourth frame image rendering were 99.3 and 97.3, respectively. The max and mini score for the fifth frame image rendering were 99.2 and 96.5, respectively. From Fig. 11 (b), in the second IEA, the max and mini rendering score of the first frame image were 99.1 and 81.7, respectively. The max and mini rendering scores for the second frame were 99.6 and 90.1, respectively. The max and mini rendering scores for the third frame were 98.7 and 87.5, respectively. The max and mini score for the fourth frame image rendering were 99.1 and 98.1, respectively. The max and mini score for the fifth frame image rendering were 99.4 and 95.5, respectively. The image smoothness and restoration results of the 3D IEA production IS method are shown in Fig. 12.

From Fig. 12 (a), the max and mini smoothness scores of the first frame image were 96.3 and 91.2 respectively. The max and mini smoothness scores of the second frame image were 97.1 and 89.5 respectively. The max and mini smoothness scores of the third frame image were 97.2 and 92.1 respectively, while the max and mini smoothness scores of the fourth frame image were 98.4 and 94.3 respectively. The max and mini smoothness score of the fifth frame image were 97.3, and 94.5 respectively. As shown in Fig. 12 (b), the max and mini smoothness scores of the first frame image were 97.4 and 93.2 respectively. The max and mini smoothness scores of the second frame image were 97.7 and 93.5 respectively. The max and mini smoothness scores of the third

frame image were 98.1 and 94.5 respectively, while the max and mini smoothness scores of the fourth frame image were 98.3 and 95.4 respectively. The max and mini smoothness score of the fifth frame image were 97.4 and 87.4 respectively.

## V. DISCUSSION

In response to the lack of content in current immersive 3D ink element animations, it is necessary to use image stitching algorithms to transform existing classic 3D ink element animations into immersive 3D ink element animations. At present, image stitching algorithms mainly focus on the stitching of monocular images, which is difficult to directly apply to the stitching of binocular images. Therefore, starting from the horizontal parallax dependence of stereoscopic perception, the research innovatively designed and developed an image stitching method for immersive 3D ink element animation production. The method was designed using stereo matching algorithms and scale invariant feature transformation algorithms, and optimized using a weighted median filtering method based on directional maps. In addition, the study also designed the specific implementation of this method from different functional modules. The analysis of the research results mainly focuses on two aspects: one is the performance verification of the algorithm used in the study, and the other is the overall effect analysis of the image stitching method. On the Tsukuba dataset, the average F1 value of the SGM algorithm is 0.9904, while the average F1 values of the SSD and SAD algorithms compared are 0.8794 and 0.8684, respectively. On the Venus dataset, the average F1 values of the three algorithms are 0.9902, 0.8892, and 0.8852, respectively. It can be seen that on different datasets, the average comprehensive evaluation value F1 of the SGM

algorithm is better than the other two comparative algorithms, indicating that the performance of the SGM algorithm is better. In the overall effect analysis of the image stitching method, the maximum rendering scores of the first ink wash animation for five consecutive frames were 98.5, 98.9, 99.5, 99.3, and 99.2, respectively. The maximum rendering scores of the second ink wash animation for five consecutive frames are 99.1, 99.6, 98.7, 99.1, and 99.4, respectively. It can be seen that the image stitching method designed by the research institute has good image rendering effects.

## VI. CONCLUSION

To avoid the lack of innovation and repeated development problems existing in the current immersive 3D IEA production, an IS method was innovatively designed and developed. The method was constructed through SM algorithm and SIFT algorithm. The experimental findings showed that on four different datasets, the error percentages of the optimized SM algorithm in non-occluded areas were 0.3885%, 0.4743%, 1.6848%, and 1.34%, respectively. The error percentages of all areas were 0.8316%, 0.8253%, 4.3235%, and 4.1760%, respectively. The optimized SM algorithm had a smaller matching error rate. On four different datasets, the running time of the SGM+WMF algorithm was 5.1354s, 5.6767s, 6.3889s, and 6.7664s, respectively. The average values of image rendering scores were 90.88, 94.22, 98.6, 98.38, and 98.1, respectively. The average image smoothness values were 94.4, 93.2, 94.52, 96.62, and 95.7, respectively, while the average restoration values were 95.18, 95.36, 96.64, 96.56, and 93.36, respectively. Although research and development have been conducted on IS a method for immersive 3D IEA production, there are still certain shortcomings, such as the further improvement of SM algorithms, which can be improved in future research.

## REFERENCES

[1] Lamberti F, Cannavo A, Montuschi P. Is Immersive Virtual Reality the Ultimate Interface for 3D Animators? Computer, 2020, 53(4):36-45.

[2] Somavarapu D H, Guzzetti D. Toward immersive spacecraft trajectory design: Mapping user drawings to natural periodic orbits. Acta Astronautica, 2021, 184(7): 208-221.

[3] Cen L, Ruta D, Qassem L M M S A, Ng J. Augmented Immersive Reality (AIR) for Improved Learning Performance: A Quantitative Evaluation. IEEE Transactions on Learning Technologies, 2020, 13(2): 283-296.

[4] Faisal S, Lin L. Green synthesis of reactive dye for ink-jet printing. Coloration technology, 2020, 136(2): 110-119.

[5] Huang X, Yang C, Chen Y, Zhu Z, Zhou L. Cuttlefish ink-based N and S co-doped carbon quantum dots as a fluorescent sensor for highly

[6] Kang Y, Wu R, Wu S, Li P, Li Q, Cao K. A novel multi-view X-ray digital imaging stitching algorithm. Journal of X-ray science and technology, 2023, 31(1):153-166.

[7] Xu J, Mou J, Liu J, Hao J. The image compression-encryption algorithm based on the compression sensing and fractional-order chaotic system. The visual computer, 2022, 38(5):1509-1526.

[8] Li L, Li T. Animation of virtual medical system under the background of virtual reality technology. Computational Intelligence, 2021, 38(1): 88-105.

[9] Sandoub G, Atta R, Ali H A, Abdel-Kader R F.A low-light image enhancement method based on bright channel prior and maximum colour channel. IET Image Processing, 2021, 15(8):1759-1772.

[10] Hosseinzadeh S, Jackson W, Zhang D, Mcdonald L, Macleod C. A Novel Centralization Method for Pipe Image Stitching. IEEE Sensors Journal, 2020, 21(10): 11889-11898.

[11] Damghani H, Mofrad F B, Damghani L. Medical JPEG image steganography method according to the distortion reduction criterion based on an imperialist competitive algorithm. IET Image Processing, 2021, 15(3): 705-714.

[12] Ro S H, Kim S H. An image stitching algorithm for the mineralogical analysis. Minerals Engineering, 2021, 169(6):106968-106979.

[13] Chen S, Jiu Z.A Method of Stereoscopic Display for Dynamic 3D Graphics on Android Platform. Journal of web engineering, 2020, 19(5): 849-863.

[14] Nie L, Lin C, Liao K, Zhao Y. Learning edge-preserved image stitching from multi-scale deep homography. Neurocomputing, 2022, 491(6): 533-543.

[15] Dai Q, Fang F, Li J, Zhang G, Zhou A. Edge-guided Composition Network for Image Stitching. Pattern Recognition, 2021, 118(9): 108019-108031

[16] Zhao Q, Ma Y, Zhu C, Yao C, Dai F. Image Stitching via Deep Homography Estimation. Neurocomputing, 2021, 450(8): 219-229.

[17] Luo X Y, Li Y, Yan J, Guan X P. Image stitching with positional relationship constraints of feature points and lines - ScienceDirect. Pattern Recognition Letters, 2020, 135(6): 431-440.

[18] Zhang G, Ling W, Duan C. Motion Damage Attitude Acquisition Based on Three-Dimensional Image Analysis. IEEE Sensors Journal, 2020, 20(20): 11901-11908.

[19] Paier W, Hilsmann A, Eisert P. Interactive facial animation with deep neural networks. IET Computer Vision, 2020, 14(6):359-369.

[20] Qi J, Liu L. The stereo matching algorithm based on an improved adaptive support window. IET image processing, 2022, 16(10): 2803-2816.

[21] Nilsson C, Nyberg J, Strmbergsson S. How are speech sound disorders perceived among children? A qualitative content analysis of focus group interviews with 10–11-year-old children. Child Language Teaching and Therapy, 2021, 37(2): 163-175.

[22] Masood F, Masood J, Zahir H, Driss K, Mehmood N, Farooq H. Novel approach to evaluate classification algorithms and feature selection filter algorithms using medical data. Journal of Computational and Cognitive Engineering, 2023, 2(1): 57-67.

# AI Animation Character Behavior Modeling and Action Recognition in Virtual Studio

Yaoyao Xu

Xiangshan Film and Television College, Ningbo University of Finance and Economics, Ningbo, 315000, China

*Abstract*—With the advancement of virtual broadcasting technology, the use of artificial intelligence animated characters in virtual scenes is becoming increasingly widespread. However, there are still a series of challenges and limitations to make the behavior of animated characters more natural, intelligent, and diverse. Therefore, this study proposes a behavior tree based animation character behavior modeling and a short-term memory action recognition method combining human geometric features. The research results indicate that when the behavior modeling model faces different obstacles, the successful avoidance rate is over 80%, and the avoidance reaction time is 0.41s-0.65s. The accuracy and loss function values of the action recognition method gradually converge to 1 and 0 with the quantity of iterations grows. For the recognition of seven types of actions, the accuracy of raising the left hand, raising the right hand, waving the left hand, and waving the right hand reaches 100%, and the recall rate of raising the right hand is 100%. The majority of action types have F-value scores above 0.9. Relative to the recurrent neural network model, the accuracy of the double-layer long-term and short-term memory model is 95.8%, which is significantly better than the former's 86.3%, showing better recognition performance. In summary, modeling and identifying the behavior of artificial intelligence animated characters can make the characters in virtual broadcasting more intelligent, natural, and realistic, thereby improving the viewing experience of virtual broadcasting, which has important practical value and research significance. This has significant practical and research value, providing insightful references for related fields.

*Keywords—Virtual broadcasting; animated characters; behavioral modeling; action recognition; behavior tree; long and short-term memory*

## I. INTRODUCTION

Virtual broadcasting technology is a cutting-edge interdisciplinary field in the fields of computer graphics and artificial intelligence, playing an important role in media such as movies, television programs, and games [1]. Through the integration of virtual broadcasting technology and artificial intelligence (AI) animated characters, viewers can experience a fully immersive audio-visual encounter [2]. However, there are still challenges to achieving more natural, intelligent, and diverse behavioral representations of animated characters [3]. Traditional virtual animation character behavior modeling relies on rule design and manual programming, which limits the ability to flexibly respond to complex environments. Action recognition methods are often limited to specific action categories and are difficult in scenarios with high real-time requirements. Therefore, this study proposes a behavior tree based animation character behavior modeling and a Long

Short Term Memory (LSTM) action recognition method that combines human geometric features. This study aims to improve the behavior and recognition abilities of AI-animated characters in virtual broadcasting, allowing them to display more natural and intelligent actions in intricate scenarios and interact with users in real-time.

Section I of the study introduces relevant technologies and methods, including existing research results on behavior modeling and action recognition, as well as research on behavior trees and LSTM. Section II provides a detailed explanation of related works. Section III is the establishment of an AI animation character behavior model, experiment and evaluation of animation character behavior model and action recognition is detailed in Section IV. Section V and Section VI delves into comparison and conclusion respectively.

## II. RELATED WORK

Behavioral modeling (BM) refers to the process of establishing and describing the behavior of individuals or systems, which has numerous applications in various fields, including AI, computer graphics, virtual reality, game development, robotics technology, etc. As the boost of computer technology and AI, significant progress and development have been made in the field of behavior modeling. Colledanchise et al. presented a method that combines automatic planners and machine learning to automatically generate a behavior tree strategy for the application requirements of industrial robots in unpredictable environments. This approach offers a practical solution for enabling robots to operate autonomously in complex environments and has significant theoretical and practical implications [4]. Kumar proposed a deep learning (DL) classifier method on the ground of children's emotions to predict children's behavior, addressing the problems in establishing a behavioral model for predicting children's current emotional activities. This provides theoretical guidance for predicting children's emotional behavior [5].

Action recognition refers to the recognition and classification of human or objects actions through technologies such as computer vision and machine learning. At present, action recognition technology has made significant progress and has been widely applied in multiple fields. Song et al. addressed the issues of complex and overly parameterized state-of-the-art models, as well as inefficient training and inference, by embedding separable convolutional layers into early fusion multi input branch networks to construct efficient graph convolutional network baselines. It is used for skeleton action recognition, effectively improving

accuracy, reducing model parameters and training costs [6]. Gharaee introduced a novel approach to recognizing human actions by employing a self-organizing mapping system. The objective was to address the problem of identifying the start and end times of online unsegmented actions for automated recognition purposes. This method can effectively extract and cluster features of action sequences, thereby achieving accurate recognition and segmentation of actions [7].

Behavior tree is a graphical tool used to model complex behaviors, commonly used in game development and virtual character control. LSTM is a special type of recurrent neural network designed to process sequential data, such as time series or text. Junaidi A et al. presented the utilization of behavior tree algorithm to effectively manage and control the diverse behaviors of NPCs for the type of side scrolling game, to enhance the fun and realism of the game. This accomplishment led to a more precise management and control of behavior, resulting in an enhanced player experience and game quality [8]. Shen et al. proposed a framework that combines bidirectional short-term memory networks and data sorting for real-time prediction of the diameter of shotcrete columns in soft soil, providing more accurate and reliable predictions for shotcrete processing in soft soil, and further improving the design of shotcrete columns [9]. Priyadarshini et al. proposed a combined model of short-term and short-term memory, CNN, and grid search to address the increase in user generated content on the Internet and the challenge of understanding emotions and emotions involved. This model helps to better understand user attitudes, viewpoints, and emotions, providing important basis for decision-making and analysis in various application scenarios [10].

In summary, scholars have conducted in-depth research on behavior modeling and action recognition. However, in many research results, the traditional virtual animation character model is not flexible and lacks real-time performance in action recognition, which needs further research. Therefore, this study proposes an animation character behavior modeling on the ground of behavior trees and an LSTM action recognition method combining human geometric features. This provides an innovative way to improve the behavior performance and action recognition ability of AI-animated characters in virtual broadcasting.

## III. ESTABLISHMENT OF AI ANIMATION CHARACTER BEHAVIOR MODEL AND ACTION RECOGNITION METHOD

As an execution method for planning models, behavior trees are widely used to construct complex AI character behaviors, enabling virtual actors to exhibit more natural, intelligent, and diverse behavior. The LSTM action recognition method involves combining geometric features of the human body with the LSTM neural network in deep learning to achieve precise recognition of actions.

### A. Establishment of AI Animation Character Behavior Model Based on Behavior Tree

AI animated characters require complex behavior and diverse decision-making in virtual broadcasting. Traditional modeling techniques, such as finite state machines, have

limitations in representation [11]. To overcome its shortcomings, this study adopts behavior tree modeling. The behavior tree has a parallel mechanism that supports hierarchical structure and node combination, making the behavior logic easier to understand. Its modular design reduces post maintenance costs, dynamically adjusts role behavior, and improves flexibility and scalability [12]. Visual perception possesses an essential influence on modeling the behavior of animated characters, simulating the visual cone of the real human eye, and setting appropriate field of view angles and ranges. The human eye's maximum visual range is $60^{\circ}$, with a comfort range limited to $30^{\circ}$. Only objects located within the visual cone can be perceived [13]. The human eye is more sensitive to dynamic objects, which allows for easier detection of their movements and changes. The visual perception model of animated characters is shown in Fig. 1.



(a)Visual stereogram      (b)Plane decomposition graph
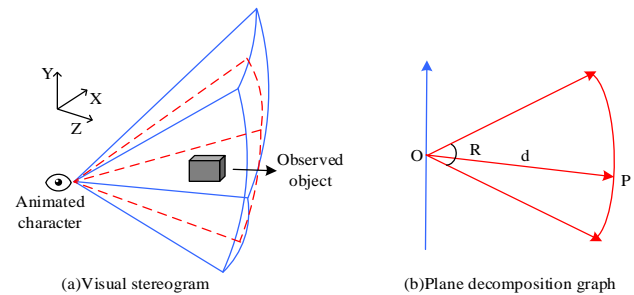
Fig. 1. Visual perception model of animated characters.

In Fig. 1, assuming that a point on the observed object is P. O represents the eye of the animated character, which is the starting point of the line of sight. R represents the angle of view. D represents the field of view distance. If the distance between OPs is less than d and the angle between OP and the Z-axis is less than half of the field of view angle R, it is assumed that the observed object is within the field of view of the animated character. In a virtual environment, animated characters need to further determine whether there is an occlusion relationship. Point occlusion method is used for line of sight detection in this study. Assuming that the world coordinate of point O is $(x_0, y_0, z_0)$ and point P is $(x_p, y_p, z_p)$, OP is represented as shown in Eq. (1) [14].

$$\begin{cases} x = x_0 + m(x_p - x_0) \\ y = y_0 + m(y_p - y_0), 0 \le m \le 1 \\ z = z_0 + m(z_p - z_0) \end{cases} \quad (1)$$

In Eq. (1), $m$ is to be solved. Assuming that there is a rectangular object between O and P as an obstruction, it projects it onto the XY plane to obtain a rectangular projection. It sets the coordinates of the four vertices as $(x_i, y_i, z_i), i = \{1, 2, 3, 4\}$, and the equations for each edge are shown in Eq. (2).

$$\frac{x - x_i}{x_{i+1} + x_i} = \frac{y - y_i}{y_i + y_i}, i = \{1, 2, 3, 4\} \quad (2)$$

It brings Eq. (2) into Eq. (1) and solve for the value of $m$. If $m$ has no solution, then OP has no intersection with the projection rectangle, indicating that the observed object is not obstructed. If $m$ has a solution, then the obtained value is taken into Eq. (1) to calculate the value of $z$. If the value of $z$ is greater than the Z coordinate value corresponding to the highest point of the obstruction, it indicates that the observed object is not obstructed. Otherwise, it is obstructed. In addition to the visual model, an auditory model should also be established. The auditory perception model of the animated character is shown in Fig. 2.

In Fig. 2, in a virtual environment, to simulate real auditory perception, the auditory range of the animated character is limited by a spherical area. Only sound located within the spherical area can be heard by the animated character [15]. It sets the auditory threshold $V_0$, assuming that the sound intensity is $V$ and the distance between the animated character and the object is $d$. Only in the case of $V/d > V_0$ an animated character hear sound and make decisions about it. On the contrary, it exceeds the auditory perception range of the animated character, and the animated character will not be able to perceive the sound. In virtual broadcasting, AI-animated characters are modeled through perception to construct their next behavior, which corresponds to the child nodes of the behavior tree, namely the animated character behavior nodes. To achieve complete action recognition and control, this study combines the perception model and behavior model into a whole, forming an animation character control behavior tree, as shown in Fig. 3.

Fig. 3 shows that in virtual broadcasting, the behavior tree of animated characters is composed of a parent node as the root node, connecting the selection node, the order node of different branches, and the standby behavior node. The standby behavior node maintains the initial behavior of the animated character. The decoration node lies beneath the order node and is accountable for continuous visual and auditory perception. Once the environmental information within the perception range of the animated character changes, the sequential logic nodes and decoration nodes come into play, interrupt standby behavior, and execute the corresponding behavior under the sequential nodes. Through this structure, animated characters make intelligent behavioral decisions on the ground of environmental changes, resulting in more realistic performance in virtual broadcasting.

### B. LSTM Action Recognition Method Combining Human Geometric Features

AI-animated characters in virtual broadcasting require action recognition ability to make corresponding action responses on the ground of user input or environmental changes. This study adopts the LSTM action recognition method that combines human geometric features [16]. AI characters obtain user action data through sensors, such as geometric features such as posture and joint position, as input. After processing by the LSTM neural network, they learn the temporal evolution patterns of action sequences and extract relevant features. Three different geometric structures of human bone point features, including 3D position difference, 3D angle difference, and bone vector angle feature, are proposed and normalized, and fused as input for the action recognition network model. The framework of the LSTM action recognition method combining human geometric features is shown in Fig. 4 [17].

Fig. 4 shows that the LSTM action recognition method is suitable for processing custom datasets containing sequences of human bone data points, and can effectively process data with temporal features. The method first extracts geometric features and normalizes human bone data points to ensure consistent data scales [18]. Then, the fused features are input into the LSTM network model to capture the dependencies and temporal correlations of action sequences. Next, the custom dataset trains the LSTM network to optimize model parameters and accurately recognize various human movements [19]. Finally, the probability distribution output by the LSTM network is converted into action classification results through the Softmax function, achieving accurate recognition and classification of human actions.



(a)Auditory stereogram      (b)Plane decomposition graph
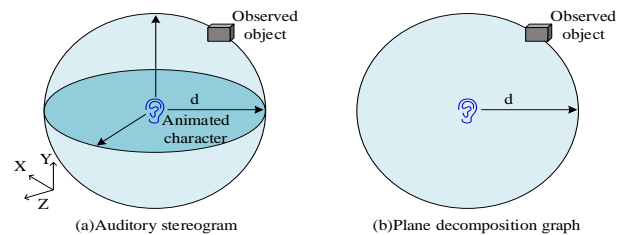
Fig. 2. Auditory perception model of animated characters.
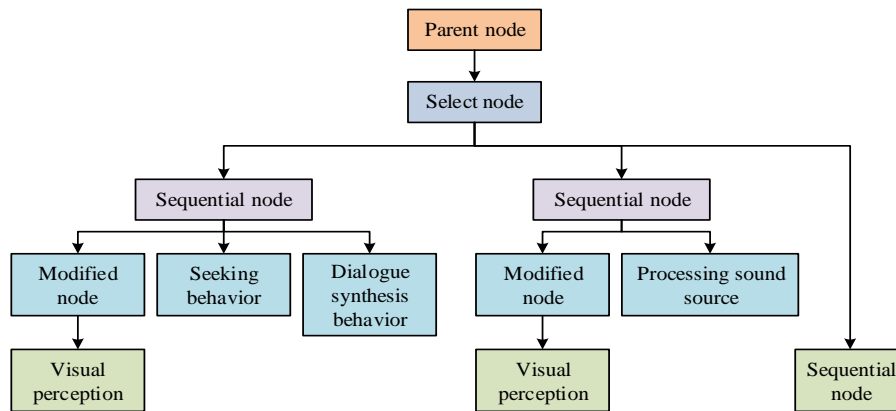


Fig. 3. The animation character controls the behavior tree.
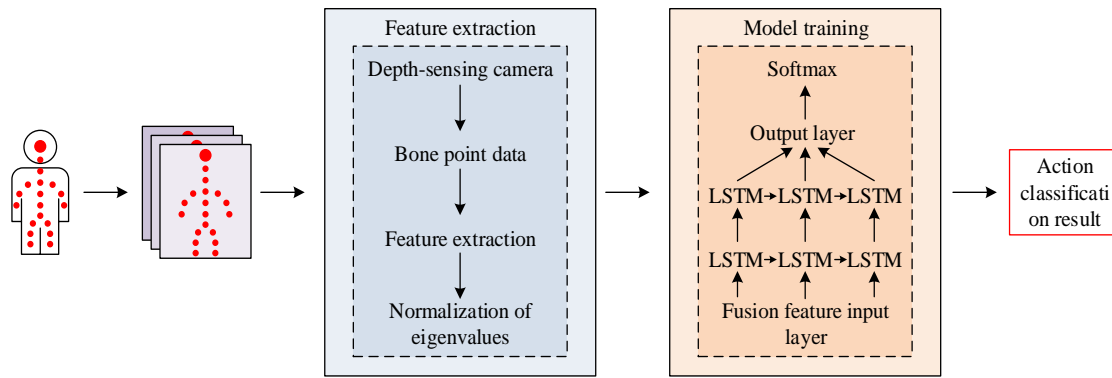
Fig. 4.   LSTM action recognition method framework combining human body geometric features.

Recurrent Neural Network (RNN) is commonly used to process serialized data, which exhibit temporal properties and cyclic transitivity. Recurrent neural networks are widely used to handle serialization problems because they can have a "memory" function that links the information of the entire network together. The expression of output layer (OLA) $h^{(t)}$ in the two-layer RNN structure is shown in Eq. (3).

$$h^{(t)} = f\left(h^{(t-1)}, x^t\right) \tag{3}$$

In Eq. (3), $x^t$ is the input of the current time (CTI) model. $f$ represents the model function, also known as the activation function. The RNN sequence length is independent of $f$ and is suitable for handling long sequence problems in different time dimensions. During network transmission, the output $h_t$ of RNN nodes at each time point is shown in Eq. (4).

$$h_t = \varphi\left(W_{xh} \cdot x_t + W_{hh} \cdot h_{t-1} + b\right) \tag{4}$$

In Eq. (4) $\varphi$ represents the activation function. $W_{xh}$ and $W_{hh}$ represent the weight matrix (WMA) in the input and output of the network nodes at the CTI, and the WMA of the hidden layer meanwhile. $b$ serves as the bias parameter. RNN transfers the output at the current moment (CMO) to the OLA and the hidden transmission at the next moment. Recursive transmission has defects, and the network gradient gradually decreases with the increase of sequence length, resulting in slower iterative updates and the issue of gradient disappearance or explosion. LSTM solves the above problems and improves the efficiency and stability of the network by adding "memory" units to the hidden layer and selectively "forgetting" long-term sequences. RNN is a standard recursive neural network, while LSTM has added three gate level control units that control the flow of information, including input gate (IGA) $i$, forgetting gate (FGA) $f$, and output gate (OGA) $o$, and has built-in hidden layer memory cell $C_t$ [20]. The FGA $f$ is utilized for controlling the degree to which information from the previous moment is retained in the current memory cell. The formula for calculating FGA $f$ at time $t$ is shown in Eq. (5).

$$f_t = \sigma\left(W_f \cdot \left[h_{t-1}, x_t\right] + b_f\right) \tag{5}$$

In Eq. (5), $W_f$ is the WMA of the FGA. $h_{t-1}$ is the hidden state of the previous moment. $x_t$ is the input at the CTI. $b_f$ is the bias parameter of the FGA. $\sigma$ serves as an S-type activation function, used to map the calculation results to the range [0,1], representing the output value of the FGA. The calculation formula for IGA $i$ is shown in Eq. (6).

$$i_t = \sigma\left(W_i \cdot \left[h_{t-1}, x_t\right] + b_i\right) \tag{6}$$

In Eq. (6), $W_i$ is the WMA of the IGA. $b_i$ is the bias parameter of the IGA. The IGA controls the degree to which the input information at the CMO updates the memory cells. The calculation formula for OGA $o$ is shown in Eq. (7).

$$o_t = \sigma\left(W_o \cdot \left[h_{t-1}, x_t\right] + b_o\right) \tag{7}$$

In Eq. (7), $W_o$ is the WMA of the OGA. $b_o$ is the bias parameter of the OGA. The OGA controls the degree to which information in memory cells is output at the CMO. The calculation of candidate memory cell $C_t^{'}$ is shown in Eq. (8).

$$C_t^{'} = \tanh\left(W_c \cdot \left[h_{t-1}, x_t\right] + b_c\right) \tag{8}$$

In Eq. (8), $W_c$ is the WMA of the input and the previous hidden state. $b_c$ is the bias parameter for candidate cells. $\tanh$ is a hyperbolic function, and the candidate memory cell is a temporary memory cell calculated at each time step to store new input information. The calculation of updated memory cells is shown in Eq. (9).

$$C_t = f_t \cdot C_{t-1} + i_t \cdot C_t^{'} \tag{9}$$

In Eq. (9), $C_{t-1}$ serves as the memory cell of the previous moment. Updating memory cells is achieved through the weighted sum of FGAs, IGAs, and candidate memory cells. The output of memory cells is shown in Eq. (10).

$$h_t = o_t \cdot \tanh\left(C_t\right) \tag{10}$$

In Eq. (10), $h_t$ represents the hidden state of LSTM at the

CTI $_t$ , which is also the output of memory cells. To better capture temporal features and improve recognition accuracy, a two-layer LSTM network model is introduced to increase network depth [21]. Fig. 5 showcases the relevant structure.
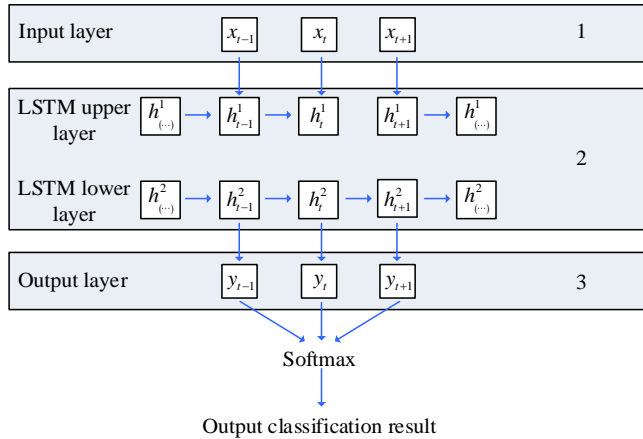


Fig. 5.  Two-layer LSTM network model.

Fig. 5 shows that in a two-layer LSTM network model, two LSTM models are set at the same level, with the upper layer (ULA) being the input layer (ILA), and the ULA LSTM model is as the input sequence. The lower layer is the OLA, and the lower layer LSTM model is used as the output model. The forward formula of the double-layer (DLA) LSTM network model is shown in Eq. (11).

$$\begin{cases} i_{l,t} = \delta\left(W_{xi}x_t + U_{hli}h_{l,t-1} + U_{h(l-1)i}h_{l-1,t} + V_{ci}c_{l,t-i} + b_i\right) \\ f_{l,t} = \delta\left(W_{xf}x_t + U_{hlf}h_{l,t-1} + U_{h(l-1)f}h_{l-1,t} + V_{cf}c_{l,t-i} + b_j\right) \\ o_{l,t} = \delta\left(W_{xo}x_t + U_{hlo}h_{l,t-1} + U_{h(l-1)o}h_{l-1,t} + V_{co}c_{l,t-i} + b_o\right) \\ C_{l,t} = f_t \cdot C_{t-1} + i_{l,t} \cdot \tanh\left(W_{xc}x_t + U_{ltc}h_{l,t-1} + U_{h(l-1)c}h_{l-1,t} + b_c\right) \\ h_{l,t} = o_{l,t} \cdot \tanh\left(C_{l,t}\right) \end{cases} \quad (11)$$

In Eq. (11), $h_{l,t-1}$ and $h_{l-1,t}$ respectively represent the hidden states of the ULA LSTM model and the lower layer LSTM model. $x_t$ is the ILA. $U_{hl}$ and $U_{h(l-1)}$ represent the weight matrices of the ULA LSTM model and the lower layer LSTM model, respectively. $b$ represents the offset parameter. All variables are classified as IGA $i$ , FGA $f$ , or OGA $o$ on the ground of $i$、$f$、$o$ in the table below. At moment $t$ , the output $y_t$ of the DLA model is shown in Eq. (12).

$$y_t = U_{hlt}h_{l,t} + b_y t \quad (12)$$

In Eq. (12), $U_{hlt}$ represents the WMA. $h_{l,t}$ serves as the hidden state of the lower layer LSTM at time $t$ . $b_y$ represents the offset parameter. The Softmax function is showcased in Eq. (13).

$$\xi_i = \frac{e^{Z^i}}{\displaystyle\sum_{J=1}^{n} e^{Z^j}} \quad (13)$$

In Eq. (13), $Z^i$ represents the $i$ -th action sequence. $J$ serves as the quantity of the action type. $n$ serves as a total of $n$ actions identified. When updating network parameters, the study adopts a cross entropy loss function, as shown in Eq. (14).

$$E\left(y_t, y_t'\right) = -y_t \log y_t' = -\sum_{t=1}^{n} y_t \log y_t' \quad (14)$$

In Eq. (14), $y_t$ represents the label of the actual action. $y_t'$ represents the label that identifies the action. The training process iteratively updates the network, leading to a gradual decrease in the loss function's value. After each update, the gradient values overlay, as demonstrated in Eq. (15).

$$\frac{\partial E}{\partial w} = \sum_{t=1}^{n} \frac{\partial E}{\partial w} \quad (15)$$

In Eq. (15), $E$ represents a loss function. $w$ represents the weight parameter in the network. Through continuous iterative updates and gradient stacking, the DLA LSTM model can gradually optimize during training and adapt to features of the data to improve recognition of temporal features with increased accuracy.

## IV. EXPERIMENTAL ANALYSIS OF AI ANIMATION CHARACTER BEHAVIOR MODELING AND ACTION RECOGNITION

To explore the effectiveness and superiority of the behavior tree based animation character behavior modeling and the LSTM action recognition method combined with human geometric features; the study started with simulation experiments and tested the collision avoidance and sound source capture indicators of the behavior modeling. Meanwhile, it conducted testing experiments on the LSTM action recognition method and compared it with the RNN model.

### A. Behavior Modeling Experiment Simulation Based on Behavior Tree

The objective of the experiment is to test the effectiveness of animation character behavior modeling on the ground of behavior trees in handling obstacles to prevent collisions and capture sound sources. Specifically, this study aims to evaluate the effectiveness of the system in avoiding collision objects and ensuring the safe movement of the modeled object in the environment. It also aims to determine whether the testing system can accurately detect and locate sound sources, thus simulating the modeled object's perception and positioning ability towards sound. The relevant situation of development environment is shown in Table I.

Table I shows that the experimental computer is configured with an AMD Ryzen 5 3600X 6-Core processor,

32GB DDR5 6000MHz memory, and is equipped with an NVIDIA GeForce RTX 3070 high-performance graphics card. This configuration meets the development requirements of the experiment and enables real-time behavior modeling and simulation in complex scenarios. Unity 3D is utilized as the game engine, supporting the development of 2D and 3D games, virtual and augmented reality applications, simulators, and animations. BM adopts the free software DAZ Studio, which provides rich functionality for creating high-quality digital characters, scenes, and animations. To achieve complex AI behavior, it uses the professional behavior tree plugin Behavior Designer. Its evaluation system performance uses collision avoidance and sound source capture metrics. The collision avoidance indicator evaluates the system's contact with collision objects in different scenarios, calculates the successful avoidance ratio and average avoidance time. The experimental results are shown in Fig. 6.

Fig. 6 shows that the successful avoidance rate is above 80% when encountering different obstacles. Among them, when facing obstacle 5, the avoidance rate at position 3 reaches 96%, which means that in most cases, the system can effectively perceive the obstacle and make timely avoidance decisions, thereby successfully avoiding collisions. The reaction time for taking avoidance actions when facing obstacles is within 0.41s-0.65s, indicating that the system has relatively fast response ability in collision avoidance. The system rapidly detects the presence of obstacles and makes appropriate decisions to evade them. The sound source capture indicator uses a virtual sound source to simulate the sound in the environment, and records the system's perception and positioning of the sound source position. It evaluates the sound source capture accuracy of the system by comparing the error between the predicted position and the actual position. The experimental outcomes are showcased in Table II.

Table II shows that the percentage of capture error for different sound sources ranges from 1.40% to 1.88%, with an average error of approximately 1.56% for sound source capture. For the given experimental data, it was observed that the percentage of error between the actual position and the predicted position is not fixed under different obstacles, but fluctuates slightly. As the distance increases, the error also increases. Overall, the predicted results (PRE) captured by the sound source are all near the actual sound source location, with small errors and within an acceptable range. This suggests that the system excels at capturing sound sources with high levels of precision and accuracy.

TABLE I. EXPERIMENTAL DEVELOPMENT ENVIRONMENT

| Hardware development platform | / | / |
|---|---|---|
| 1 | Computer processor | AMD Ryzen 5 3600X 6-Core Processor 3.80 Ghz |
| 2 | Computer memory | 32GB DDR5 6000MHz |
| 3 | Computer graphics card | NVIDIA GeForce RTX 3070 |
| Software development platform | / | / |
| 1 | Game engine | Unity 3D |
| 2 | Modeling software | DAZ Studio |
| 3 | Action number plug-in | Behavior Designer |



(a) The result of the experiment of the ratio of avoidance times

(b) The result of avoidance time experiment
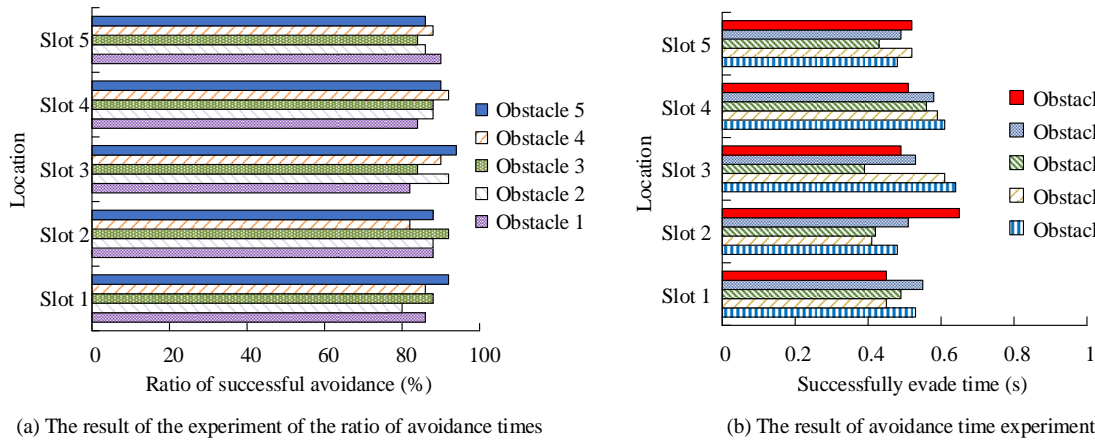
Fig. 6. Proportion of successful avoidance and average avoidance time of the system.

TABLE II. TEST RESULTS OF SOUND SOURCE CAPTURE EXPERIMENT

| Sound source | Actual location of the sound source (m) | Sound source predicted bearing (m) | Error (%) |
|---|---|---|---|
| 1 | 5.62 | 5.71 | 1.60 |
| 2 | 8.49 | 8.33 | 1.88 |
| 3 | 2.61 | 2.62 | 1.14 |
| 4 | 7.36 | 7.49 | 1.77 |
| 5 | 4.28 | 4.34 | 1.40 |

## B. Experimental Analysis of LSTM Action Recognition Method

The experiment used the UCF101 dataset, created by a team of researchers at the University of Central Florida, and a custom dataset, which included 101 different categories of movements and more than 13,000 video clips covering movements of a variety of daily life and sports. The latter was gathered utilizing a half-body camera and comprised of 12 crucial bone points and seven fundamental movements from a total of 10 participants. The cross-validation numbers are 1-10, the training set contains 634 action sequences, and the test set contains 618 action sequences. The collected 3D position difference feature is an 11-dimensional vector, the 3D Angle difference feature is a 12-dimensional one, and the bone vector Angle feature is an 8-dimensional one. To reduce the risk of overfitting, 0.1 random inactivation is added to the hidden unit of the network. The study first conducted fusion comparative experiments on three different features: 3D position difference feature, 3D angle difference feature, and bone vector angle feature. It records three different features: 3D position difference feature, 3D angle difference feature, and bone vector angle feature, which are A, B, and C. The fusion feature of A and B is D, and the fusion feature of the three features is E. The recognition rate results obtained from the experiments are shown in Table III.

TABLE III.    MODEL RECOGNITION RATE WITH FEATURE FUSION

| Input feature vector | Maximum recognition rate (%) | Minimum recognition rate (%) | Average recognition rate (%) |
|---|---|---|---|
| A | 78.12 | 72.48 | 75.23 |
| B | 72.54 | 51.89 | 65.65 |
| C | 86.39 | 67.73 | 76.45 |
| D | 89.45 | 76.28 | 84.32 |
| E | 98.23 | 92.46 | 95.03 |

Table III shows that the recognition rate for A is fairly consistent, ranging from a high of 78.12% to a low of 72.48%. The difference between the highest and lowest recognition rates of B is significant, making it the most unstable of the five features. Meanwhile, the average recognition rate is only

65.65%, which is also the lowest. The performance of C and D is average, but D, which combines the two features, has a marked enhancement relative to C. For E, the fusion of three features resulted in a maximum recognition rate of 98.23%, a minimum recognition rate of 92.46%, and an average recognition rate of 95.03%, indicating a significant improvement. Therefore, E was utilized as the input for the double-layer LSTM network model to obtain the accuracy change curve and loss function value (LFV) change curve, as shown in Fig. 7.

In Fig. 7, the accuracy curve shows that the accuracy gradually converges to 1 with an increase in iterations, suggesting perfect classification performance for the training data. The LFV in the LFV change curve gradually converges to 0 with the quantity of iterations grows, indicating that the error between the PRE of the model and the actual labels is effectively reduced during the training. This research uses IDLE for stationary and WALK for walking. RUN stands for running. LHU means raising the left hand. RHU stands for raising the right hand. WLH means waving to the left. WRH means waving to the right. The study evaluated and identified seven actions and obtained their accuracy, recall, and F1 score (F1 Score) results, as shown in Fig. 8.

Fig. 8 shows that the accuracy of LHU, RHU, WLH, and WRH actions is 100%, indicating that the model has no errors in the recognition and prediction of these four actions. The recall rate of action type RHU is also 100%, indicating that the model has excellent capture ability for this action and has not missed any real positive examples. The F1 Score of most action types is above 0.9, indicating that the model performs well on multiple indicators and has good classification performance. The recognition rate of action types WALK and RUN is relatively low because they belong to repetitive dynamic feature sequences. Furthermore, during the capture process, only the upper body mode was employed, thus neglecting bone points such as the knees and ankles, which offer improved distinguishing features between these movements. For demonstrating the superiority of the DLA LSTM model, comparative experiments were conducted with the RNN model. The results are shown in Fig. 9.



(a) The relationship between accuracy and the number of iterations



(b) The relationship between Loss function value and the number of iterations
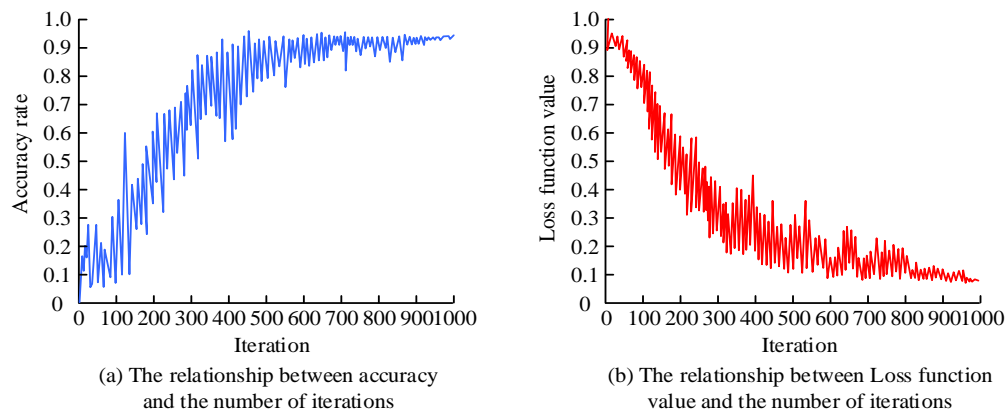
Fig. 7.    Accuracy curve and LFV curve of two-layer LSTM network model.
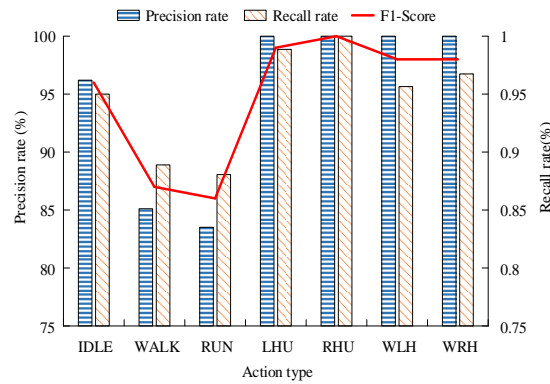
Fig. 8.    Model recognition result.



(a) Two-layer LSTM model confusion matrix



(b) RNN model confusion matrix



(c) Comparison of F1-Score of two models

Fig. 9.    Comparison of experimental results between two-layer LSTM model and RNN model.

Fig. 9 shows that the RNN model lacks a "rgetting unit" resulting in a significant increase in misclassification of actions during the recognition process compared to the DLA LSTM model. The diagonal elements of the confusion matrix represent the recall rate of the current model, which is the probability of accurately predicting actions. When comparing the F1 Score values of the DLA LSTM model and the RNN model, it is evident that the LSTM model outperforms the RNN model in all seven classification actions. After calculation, the accuracy of the DLA LSTM model is 95.8%, and the accuracy of the RNN model is 86.3%, indicating that the DLA LSTM model has better recognition performance.

## V.    COMPARISON

The conclusions of study [22] were compared with the conclusions of the research, in which study [22] mentioned the application of transformer-based deep neural networks to human action recognition, and the overall success rate reached 94.96% for six kinds of actions. The accuracy rate of the two-layer LSTM model proposed in this research was 95.8%, surpassing that of the aforementioned [22] method, thus demonstrating the superiority of this study.

## VI. CONCLUSION

In response to the limitations in traditional virtual animation character behavior modeling and action recognition methods, this study proposes a behavior tree based animation character behavior modeling and an LSTM action recognition method combining human geometric features, and verifies the performance and effectiveness of both methods. The research results indicate that when the behavior modeling model faces different obstacles, the proportion of successful avoidance is over 80%, and the avoidance response time is within 0.41s-0.65 seconds, indicating that the system can effectively perceive obstacles and make avoidance decisions in a timely manner. The accuracy and LFVs of the LSTM action recognition method gradually converge to 1 and 0 as the number of iterations increases. This indicates the model's ability to perform perfect classification on the training data and effectively reduce the error between the PRE and real labels during the training process. Meanwhile, the LSTM action recognition method achieves 100% accuracy in identifying seven types of actions, including LHU, RHU, WLH, and WRH. The RHU achieved a recall rate of 100%, and most action types received an F1 Score higher than 0.9. In the comparative experiment between the DLA LSTM model and the RNN model, the accuracy of the DLA LSTM model was 95.8%, and the accuracy of the RNN model was 86.3%, demonstrating that the DLA LSTM model has better recognition performance. Overall, the behavior modeling and action recognition methods studied and designed have high effectiveness and certain advantages, providing an effective solution for AI animation character behavior modeling and action recognition in virtual broadcasting. However, this study used upper body mode for behavior capture, ignoring bone points such as knees and ankles that are more likely to distinguish between the "walking" and "running" categories, and further discussion is needed.

## REFERENCES

[1] Jones D, Lotz N, Holden G. A longitudinal study of virtual design studio (VDS) use in STEM distance design education. International Journal of Technology and Design Education, 2021, 31(4): 839-865.

[2] Kaul V, Enslin S, Gross S A. History of artificial intelligence in medicine. Gastrointestinal endoscopy, 2020, 92(4): 807-812.

[3] Dvorožňák M, Sýkora D, Curtis C, et al. Monster mash: a single-view approach to casual 3D modeling and animation. ACM Transactions on Graphics (ToG), 2020, 39(6): 1-12.

[4] Colledanchise M, Natale L. On the implementation of behavior trees in robotics. IEEE Robotics and Automation Letters, 2021, 6(3): 5929-5936.

[5] Kumar D T S. Construction of hybrid deep learning model for predicting children behavior based on their emotional reaction. Journal of Information Technology and Digital World, 2021, 3(1): 29-43.

[6] Song Y F, Zhang Z, Shan C, Wang L. Constructing stronger and faster baselines for skeleton-based action recognition. IEEE transactions on pattern analysis and machine intelligence, 2022, 45(2): 1474-1488.

[7] Gharaee Z. Online recognition of unsegmented actions with hierarchical SOM architecture. Cognitive Processing, 2021, 22(1): 77-91.

[8] Junaidi A, Yunus A, Wiguna A S. Implementasi Behavior Tree Pada Perilaku Npc Di Game Sidescroller. Kurawal-Jurnal Teknologi, Informasi dan Industri, 2021, 4(2): 92-103.

[9] Shen S L, Atangana Njock P G, Zhou A, Lyu H M. Dynamic prediction of jet grouted column diameter in soft soil using Bi-LSTM deep learning. Acta Geotechnica, 2021, 16(1): 303-315.

[10] Priyadarshini I, Cotton C. A novel LSTM–CNN–grid search-based deep neural network for sentiment analysis. The Journal of Supercomputing, 2021, 77(12): 13911-13932.

[11] Fang Y, Luo B, Zhao T, He D, Jiang B, Liu Q. ST-SIGMA:Spatio-temporal semantics and interaction graph aggregation for multi-agent perception and trajectory forecasting. CAAI Transactions on Intelligence Technology, 2022, 7(4):744-757.

[12] Chen-Kraus C, Raharinoro N A, Lawler R R. Terrestrial Tree Hugging in a Primarily Arboreal Lemur (Propithecus verreauxi): a Cool Way to Deal with Heat? International Journal of Primatology, 2023, 44(1): 178-191.

[13] Wu C, Cha J, Sulek J, Zhou T, Sundaram C P, Wachs J, Yu D. Eye-tracking metrics predict perceived workload in robotic surgical skills training. Human factors, 2020, 62(8): 1365-1386.

[14] Navaneethan S, Sreedhar P S S, Padmakala S, Senthilkumar C. The Human Eye Pupil Detection System Using BAT Optimized Deep Learning Architecture. Comput. Syst. Sci. Eng., 2023, 46(1): 125-135.

[15] Denham S L, Winkler I. Predictive coding in auditory perception: challenges and unresolved questions. European Journal of Neuroscience, 2020, 51(5): 1151-1160.

[16] Yan X, Weihan W, Chang M. Research on financial assets transaction prediction model based on LSTM neural network. Neural Computing and Applications, 2021, 33(2): 257-270.

[17] Xu S, Rao H, Peng H, Jiang X, Guo Y, Hu X, Hu B. Attention-based multilevel co-occurrence graph convolutional LSTM for 3-D action recognition. IEEE Internet of Things Journal, 2020, 8(21): 15990-16001.

[18] Lei Y. Research on microvideo character perception and recognition based on target detection technology. Journal of Computational and Cognitive Engineering, 2022, 1(2): 83-87.

[19] Zheng H, Lin F, Feng X. A hybrid deep learning model with attention-based conv-LSTM networks for short-term traffic flow prediction. IEEE Transactions on Intelligent Transportation Systems, 2020, 22(11): 6910-6920.

[20] Essien A, Giannetti C. A deep learning model for smart manufacturing using convolutional LSTM neural network autoencoders. IEEE Transactions on Industrial Informatics, 2020, 16(9): 6069-6078.

[21] Singh K, Malhotra J. Two-layer LSTM network-based prediction of epileptic seizures using EEG spectral features. Complex & Intelligent Systems, 2022, 8(3): 2405-2418.

[22] Hou Y, Wang L, Sun R, et al. Crack-across-pore enabled high-performance flexible pressure sensors for deep neural network enhanced sensing and human action recognition. ACS nano, 2022, 16(5): 8358-8369.

# An Integrated, Bidirectional Pronunciation, Morphology, and Diacritics Finite-State System

Maha Alkhairy

University of Massachusetts Amherst,
Amherst, MA, USA

Afshan Jafri

King Saud University,
Riyadh, Saudi Arabia

Adam Cooper

Northeastern University,
Boston, MA, USA

*Abstract*---A bidirectional phonetizer, morphologizer, and diacritizer pipeline (FSPMD) for modern standard Arabic (MSA) that integrated pronunciation, concatenative and templatic morphology, and diacritization were developed. Grammar and segmental phonology rules were applied in the forward direction to ensure the order of the proper rules, which were supplemented with special backward direction rules. The FSPMD comprises bidirectional finite-state transducers (FSTs) consisting of an ordered composition of FSTs, unordered parallel FSTs, unioned FSTs, and for validity, finite-state acceptors. The FSPMD has unique, innovative features and can be used as an integrated pipeline or standalone phonetizer (FSAP), morphologizer (FSAM), or diacritizer (FSAD). As the system is bidirectional, it can be used in forward (generation, synthesis) and backward (analysis, decomposition) directions and can be integrated into systems such as automatic speech recognition (ASR) and language learning tools. The FSPMD is rule-based and avoids stem listings for morphology or pronunciation dictionaries, which makes it scalable and generalizable to similar languages. The FSPMD models authentic rules, including fine granularity and nuances, such as rewrite and morphophonemic rules, subcategory identification and utilization, such as irregular verbs. FSAP performance regarding text from the Tashkeela corpus and Wikipedia demonstrated that the pronunciation system can accurately pronounce all text and words, with the only errors related to foreign words and misspellings, which were out of the system's scope. FSAM and FSAD coverage and accuracy were evaluated using the Tashkeela corpus and a gold standard derived from its intersection with the UD_PADT treebank. The coverage of extraction of root and properties from words is 82%. Accuracy results are roots computed from a word (92%), words generated from a root (100%), non-root properties (97%), and diacritization (84%). FSAM non-root results matched and/or surpassed those from MADAMIRA; however, root result comparisons were not conducted because of the concatenative nature of publicly available morphologizers.

*Keywords---Computational linguistics; phonology; morphology; modern standard Arabic; diacritization; text-to-speech; language learning tools*

## I. Introduction

Natural language processing technologies, such as automatic speech recognition (ASR) systems, rely on pronunciation dictionaries that provide word listings and corresponding phone pronunciations for both training and recognition. In the ASR training phase, an orthographic text passage is transformed into its phonetic transcription (pronunciation), which comprises a sequence of phonemes or phones. In the recognition phase, the phonetic transcription is transformed into its associated word sequence orthographic text (1).

Because effective ASR requires a large dictionary that lists the words and their pronunciation, the system perplexity increases, and the accuracy declines. One possibility to reduce the size for languages that have deep orthography and highly irregular mapping, such as English, French, and Danish, is to list the affix and stem pronunciations rather than the words; however, this requires a concatenative morphologizer (prefix, stem, and suffix). At the other end of the spectrum, languages that have shallow orthography (phonetic languages) and a one-to-one correspondence between the letters and phonemes, such as Finnish and Turkish, only require a very simple dictionary of letters and the associated phonemes. Because middle-spectrum languages, such as Russian, German, and Spanish, have complex correspondences between the letters and pronunciation, they are not amenable to rules [1] (2).

However, other languages in the middle spectrum, such as Arabic and Hebrew, do have rules-based pronunciation, which means that rule-based transducers between the words and their phonemic transcriptions could resolve the need for large pronunciation dictionaries. If a transducer is bidirectional, it could be used for both the ASR training and recognition phases. In the backward direction, in which a phonetic sequence is mapped to an orthographic text, a word acceptor based on morphemes is needed to avoid invalid words, the use of which could avoid large word lists that would require an integrated phonetizer and morphologizer. While building a more efficient, accurate ASR could be a valid motivation for designing a bidirectional rule-based pronunciation transducer (phonetizer), such automata would be useful in its own right as it could be applied to other domains, such as text-to-speech synthesis, that require the identification of both suprasegmental features and segmental phonology. In addition to designing and constructing a bidirectional rule-based phonologizer that maps the relationships between orthographic text and its phonetic transcription, this study also developed a bidirectional concatenative (prefixes, stems, suffixes) and templatic (roots, patterns) morphologizer that generates words from morphemes and decomposes words into morphemes. Templatic morphology is another major feature not present in languages such as English.

Besides being important in its own right in multiple technologies, there are two main reasons a morphologizer is required in phonetizers: as an acceptor to filter out invalid words without the need for a large word list and as a phonological morphology-based rules regulator to determine whether a word is a noun or a verb to reduce pronunciation ambiguity.

In languages such as Arabic and Hebrew, the written script

---

is either undiacritized or diacritized. As phonetizers and morphologizers generally require diacritized text, a diacritizer is also needed to complete the pipeline. In the system developed in this study, the diacritizer is independent of the phonetizer and morphologizer; however, it uses the same constructs as the morphologizer.

The links between morphology, phonology, morphology, and diacritics result in an integrated system. Therefore, this study proposes a method and structure that can exploit the innate grammar of a language. While Arabic is used as the demonstration language in this study, the proposed method can be equally applied to other such languages. Semitic languages, such as Arabic and Hebrew, have form-based morphology and rules-based pronunciation and are usually undiacritically written (3).

An integrated bidirectional finite-state (FSPMD) system was designed and constructed that incorporates a phonetizer (FSAP), a morphologizer (FSAM) that can work with both diacritized and undiacritized text, and a diacritizer (FSAD). The various linguistic and segmental phonological rules were fully incorporated and finite-state transducers (FST) were solely employed to build the system; therefore, it was not necessary to include the additional features found in other systems, such as two-level finite states and flags.

In the forward direction, the FSAP transforms a diacritized passage into its corresponding pronunciation; FSAM generates words from the patterns, roots, prefixes, and suffixes; and FSAD inserts diacritics into undiacritized words. In the backward direction, the FSAP produces a text passage for a sequence of phones; FSAM decomposes the words into their prefixes, patterns, roots, suffixes, and linguistic features, such as gender and part of speech; and FSAD strips the diacritics from diacritized words. The FSAM can also work as an acceptor for morphologically valid words

The FSPMD, therefore, connects phonetic transcriptions and diacritization to morphology to create a tight system that among other constraints, limits words corresponding to a pronunciation when there is an absence of listings. The FSPMD's bidirectional pipeline synthesizes words from affixes, patterns, and roots, computes the pronunciation from texts based on segmental phonological units, and diacritizes words, and in the opposite direction, analyzes a word into its morphemes, transforms pronunciation into text, and undiacritizes words.

This study excluded end-of-word diacritics as these are governed by syntactic rules that are unable to be formulated as regular expressions that can be realized as finite-state transducers (FSTs), that is, they require higher-order formal language, such as context-sensitive grammar. Particular attention was paid to authentic grammar rules and many details and nuances were incorporated, such as the effects of text marks in phonology and the inclusion of rewritten rules for the morphological orthography.

The remainder of this paper is organized as follows. Section II details the problem and the integrated architecture, Section III presents the phonetizer, Section IV presents the morphologizer, and Section V presents the diacritizer. Appendix A presents the phonetizer and morphologizer literature reviews. Appendix B presents additional phonetizer and morphologizer evaluation results. Transliterations of Arabic to Roman letters were not used to reduce confusion. Supplementary material 1 is a compendium for Arabic orthography, phonetics, and morphology and provides details not necessary to understand the main paper. Supplementary material 2 gives the finite-state automata and their earlier usages in linguistics and phonology and a related literature survey.

## II. PROBLEM FORMULATION AND INTEGRATED ARCHITECTURE

An orthographic text is a sequence of characters that make up words and marks such as tabs, text beginnings, and commas. An Arabic word comprises a sequence of graphemes that include alphabetic and non-alphabetic letters and diacritics. In addition to syntax, which governs the end-of-word diacritics, diacritized text has all the diacritics mandated by the associated spelling and morphological rules; however, undiacritized texts only have Shaddah and sometimes Tanween and Sukoon as diacritics. Because syntactic processing may not be realized by FSTs, in this study, the undiacritized Arabic texts also included end-ofword diacritics. A phonetic transcription (pronunciation) is a sequence of phones consisting of phonemes and fermatas that represent pauses of various durations and continuation. These graphemes, marks, phonemes, and fermatas are described in Supplementary material I along with the mappings between the marks and fermatas. If there is more than one realization based on the context, the phonetic transcriptions may also contain an allophone variation of a phoneme.

Phonetically transcribing an orthographic text produces phonemes and fermatas that depend on both graphemes and marks, that is, the transformation of phonetic transcription to orthographic text depends on both phonemes and fermatas, which is why the fermata plays a more important transformation role in Arabic than in other languages.

The proposed system has various FSTs to transform the input sequences into output sequences. The transducer also acts as an acceptor, which produces a FALSE notification if the input is not valid according to the transducer rules. As the forward direction FST was designed to utilize linguistic grammar rules, depending on the particular FST, the forward direction could be either generation/synthesis or analysis/decomposition. Bidirectional FSTs were employed to enable generation as well as analysis using analysis rules. This was made possible by the method used to construct the FSTs, which incorporated some unidirectional limiting rules exceptions and some additional rules for the opposite direction only. The rules were written as regular expressions, which were then transformed into non-probabilistic FSTs using the open-source Foma compiler (4).

The FSAP mapped between the diacritized texts and the phonetic transcriptions, with the forward direction producing the pronunciation from the diacritized orthographic texts, which was represented by International Pronunciation Association (IPA) and fermata symbols. Because the phonetizer can realize segmental rules, it did not embody phonological suprasegmentals, such as syllables, stress, or intonation. The FSAD mapped between the diacritized words and the corresponding undiacritized words, with the forward direction generating diacritized words from an undiacritized word. The FSAM mapped between the words and associated morphemes (pattern, root, prefix, suffix), with the backward direction generating words

from the morphemes. While these FSTs were constructed from multiple FST components, as described in the various sections, each can also be used as a standalone system.

The three FSTs were integrated into a pipeline structure to compute the phonetic transcriptions for the undiacritized (or diacritized) texts or to decompose an undiacritized word into its morphemes. The integrated pipeline system's (Fig. 1) forward and backward direction functions are detailed in the following.
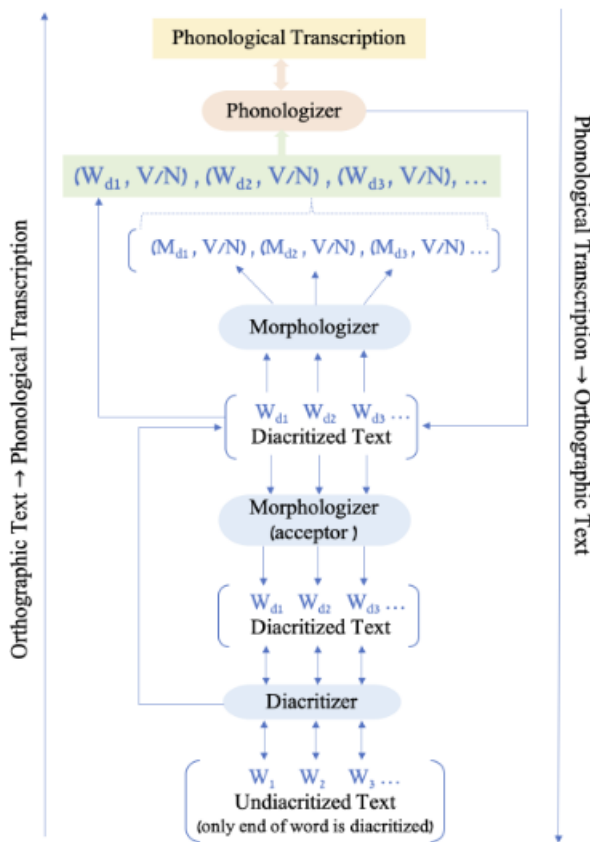


Fig. 1. Bidirectional integrated system mapping between the orthographic undiacritized text and the phonetic transcription (pronunciation). M refers to morphemes (prefix, root, suffix, and pattern), N refers to nouns, and V refers to verbs, as these affect the pronunciation.

In the forward direction, the system takes four steps to produce a phonetic transcription of an undiacritized text: (1) the diacritizer maps a given sequence of undiacritized words into diacritized words; (2) the morphologizer extracts the morphemes (prefix, root, suffix, pattern) and morphological properties (noun or verb) of each word in the sequence; (3) the system then concatenates the morphologizer and diacritizer results to produce a sequence of diacritized words and the associated morphological properties; and (4) finally, the concatenation sequence is input into the phonetizer, which produces the phone sequences.

In the backward direction, the pipeline system takes three steps to produce the undiacritized and diacritized orthographic

texts to be input into the phonetic transcription: (1) the phonetizer used in the reverse direction produces multiple diacritized word sequences from the phone sequence; (2) the morphologizer, which is used as an acceptor, filters out the morphologically incorrect diacritized word sequences and produces a set of valid diacritized texts; and (3) finally, the diacritizer used in the reverse direction undiacritizes the diacritized word sequences to produce an undiacritized text.

### III. Phonetic Transducer (FSAP)

The phonetic transducer was constructed using a combination of an ordered composition of FSTs and unordered parallel FSTs, with the finite-state automata (FSAs) being the acceptors to define the grapheme, marker, phoneme, and fermata subsets. The unordered FSTs embodied non-contextual rules and the ordered FSTs realized the contextual grammar, which required a thorough and precise ordering of the rules to ensure precise results.

In contrast to the current approaches outlined in Appendix A, FSTs rather than procedural methods were utilized, which avoided the need for a two-level FST that makes multiple transformations in favor of a single level; syllabic structures to compensate for shortcomings in the realization of the rule; the incorporation of context-dependent rules in a specified order, which is generally ignored; and the realization of all MSA rules, including those related to text markers, which can significantly effect phonetization.

Geminated consonants and long vowels were also considered phonemes in their own right. Previous studies(5) have tended to consider gemination by doubling a singleton consonant or mapping it into its singleton version, which has been shown to be phonetically inaccurate, as demonstrated by geminated plosives that have a single voice onset time and release. Similarly, long vowels have previously been dealt with by doubling the short version; however, the spectral characteristics of long vowels are noticeably different from their short vowel counterparts(5).

Rather than applying simplifications to these rules, special attention was paid to the precise complex rules regarding Wasl (ب ف ك و) and Illah (ا و ي) characters, including those in the Sukoon (ـْ) context. Rules regarding the noun versus verb factors in the pronunciation of diacritized words were also considered as diacritized words still have some pronunciation ambiguity in Alif Wasl (ا).

The following subsections present the contextual and non-contextual orthography: phoneme mappings and contextual phonemes; allophone rules and backward phonemes; and orthography results. The section ends with the phonetic transducer evaluations.

### A. Orthography: Phoneme Mappings

The orthographic and phonetic representation mappings were divided into non-contextual and contextual rules. The first two subsections present the non-contextual diacritics; vowel and character and phoneme mappings; and the latter three sections present the contextual letters; the phoneme mappings and pronunciation rules governed by a word's part of speech, such as noun or verb. The markings affecting the way the letter/diacritic is pronounced are also detailed in the following rules.

*1) Diacritics: vowels mappings:* A Harakat (ﹷ) grapheme can be mapped to its corresponding short vowel (/a/, /u/, and /i/) in all contexts; however, it is not pronounced (/•/) when it precedes its corresponding 'vowel characters' (ي), (و), (ى' ا). A Tanween (ﹸ) grapheme only diacritizes the end of words and generally maps to its corresponding vowel when followed by /n/ (/a/ / n/, /u/ /n/, /i/ /n/); however, Tanween is not pronounced (/•/) if it diacritizes a word that ends the sentence.

*2) Non-contextual characters: phoneme mapping:* The diacritic ﹽ (shaddah) causes a gemination in the sound of the preceding letter it diacritizes, and ﹿ maps to a zero duration pause /Φ/. The Hamza set (ؤ ئ إ أ ء) is pronounced as /ʔ/, and the other mappings are as follows: ('ː /aː/), (آ: /ʔaː/), (ب: /b/), (ت: /t/), (ث: /θ/), (ج: /dʒ/), (ح: /ħ/), (خ: /χ/), (د: /d/), (ذ: /ð/), (ر: /r/), (ز: /z/), (س: /s/), (ش: /ʃ/), (ص: /sˤ/), (ض: /dˤ/), (ط: / tˤ /), (ظ: /ðˤ/), (ع: /ʕ/), (غ: /ʁ/), (ف: /f/), (ق: /q/), (ك: /k/), (م: /m/), (ن: /n/), (ه: /h/).

*3) Contextual letters: phoneme mapping:* The context determines the pronunciation for (ل، ا، ي، و، ى، ة). The rules are presented from the simplest to the most complex for the Wasl letters (ك ل ت ب و), the Alef Wasl (ا), the definite article (ال), and the other rules. The following are the contextual mappings for the letters and letter combinations.

The letter ة is always at the end of a word followed by a Haraka and maps to /t/ or /h/. ة : /t/ if it is in a word in the middle/start of a sentence and not followed by ﹿ; ة : /h/ if followed by ﹿ or in a word that ends a sentence. The letter ى always ends a word and maps to /aː/ or /a/; ى maps to /a/ if it ends in a word that precedes a word that starts with ا, and ى, and /aː/ if it is in a word that ends a sentence or precedes a word that doesn't start with ا.

The letter و maps to /w/, /wː/ or /uː/. و : /w/ if followed by a diacritic other than ﹿ and preceded by ﹿ; و : /wː/ if followed by ﹿ and preceded by ﹿ ;, and و: /uː/ if preceded by ﹿ. The letter ي maps to /j/, /jː/, or /iː/. ي : /j/ if preceded by ﹿ or ﹿ and followed by a diacritic other than ﹿ ; ي : /jː/ if preceded by ﹿ or ﹿ and followed by a diacritic other than ﹿ; and ي: /iː/ if preceded by ﹿ.

The letter ا maps to /ʔ/ or is not pronounced /•/. ا: /ʔ/ if it starts a word and is followed by a Harakah; اː, and /•/ if it is preceded by a Wasl letter (ك ل ت ب و). The combination ﹷـ maps to /a/ if it ends a word, and maps to /aː/ if it is between letters.

The letter ل maps to /l/ or /ɛ/ (not pronounced) when it is part of the definite article (ال); otherwise, it is pronounced /l/. The letter combination ال (the definite article) maps to /ʔal/, /ʔa•/, /•l/, or /•/ (not pronounced), ال: /ʔal/ if it is followed by a Lunar letter; ال: /ʔa•/ if it is followed by a Solar letter, ال: /•l/ if it is preceded by a Wasl letter, and ال: /•/ if it is preceded by a Wasl letter and followed by a Solar letter. The pronunciation of ا and ال at the beginning of a word also depends on whether the word is a verb or a noun, as detailed in Subsection III-A4.

*4) Noun and verb rules pertaining to Alif Wasl:* When it occurs at the start of the word without diacritization and as part of the spelling, the pronunciation of Alif Wasl (ا) is ambiguous and requires knowledge of the word's part of speech, particularly whether it is a noun or verb. Specifically, the situations are as follows: (1) ا: /ʔa/ if ا is part of ال at the beginning of a verb and not a noun, that is, it is not treated like ال the definite article; for example, الْعَب : /ʔalʕab/ and الْجُمْ : /ʔaldʒum/; (2) ا : /ʔu/ if ا is at the beginning of a verb in which the third letter is diacritized with ﹹ ; for example, اكْتُبْ : /ʔuktub/; (3) ا: /ʔi/ if ا is at the beginning of a noun and not part of the definite article (ال); for example, امْرُؤٌ : /ʔimruʔ/, اسم : /ʔism/, and ابْن : /ʔibn/.

### B. Contextual Phoneme: Allophone Mappings

Multiple phoneme to allophone mappings exist and have several variations, two of the most prominent of which are described here. The first is pharyngealization, which produces a pharyngeal counterpart (if it exists) of a phoneme followed by a pharyngeal phoneme. The second is homorganic nasal place assimilation, which changes a nasal phoneme. For example, the alveolar nasal /n/ is pronounced as the bilabial nasal /m/ if it is followed by the voiced bilabial /b/ or the bilabial nasal /m/. Table I gives some examples of these rule occurrences.

### C. Phonetic Transcription to Orthographic Text

The previous subsections presented the bidirectional mappings formulated in the forward direction. As mentioned, the FST's bidirectional nature allows the system to map from phonetic transcription to orthographic text. Some mappings, however, need to be explicitly expressed in the backward direction only. Table II provides a few examples generated by the phonetizer.

The rules that lead to the deletion of characters can interfere with the rules and cause an infinite loop, that is, no results. This can be resolved by including a special symbol to indicate deletion and by not applying the deletion in the reverse direction. Because some of the outputs in this direction were not valid words due to the deletions that occur in pronunciation and the lack of word lists, the produced words were input into the morphologizer in the analysis direction to treat the lack of analysis as a rejection.

### D. FSAP Evaluation

In the absence of a pronunciation corpus with a sufficient number of examples to gain a numeric accuracy and recall evaluation, fully diacritized pronunciation examples, which were independently verified by a linguist, were produced to test the FSAP's scope and accuracy, with the performances being assessed based on: 1) individual words and small sentences with the associated pronunciation to test the specific context and check the inclusion and accuracy of all rules; 2) passages from Tashkeela(6) to test the ability to deal with multiple contexts at a time and to handle unknown words; and 3) examples from Wikipedia [2] [3] with the associated transcription to assess the validity of the system. The evaluation of the examples demonstrated that the pronunciation system was able to accurately pronounce all text and words, with the only errors being foreign words and misspellings, such as a missing Mad character, which was out of the system scope.

---

[2]https://en.wikipedia.org/wiki/Varieties_of_Arabic
[3]https://en.wikipedia.org/wiki/Arabic_phonology

TABLE I. SAMPLE ALLOPHONIC CHANGES IN MODERN STANDARD ARABIC

| Word | Gloss | Phonemic | Allophonic | Change |
|---|---|---|---|---|
| استصلح | consider useful | /ʔis.tasˤ.la. ħa/ | [ʔisˤ.tasˤ.la.ħa] | pharyngealization |
| فرعون | Pharaoh | /fir.ʕawn/ | [ firˤ.ʕawn ] | pharyngealization |
| انبعث | regain one's strength and vividness | /ʔin.ba.ʕa.θa/ | [ʔim.ba.ʕa.θa] | Homorganic nasal place assimilation |
| من بعد | after | /min baʕ.di/ | [mim‿baʕ.di] | Homorganic nasal place assimilation |

TABLE II. PHONETIC TO ORTHOGRAPHIC TRANSFORMATION: Φ: ZERO DURATION PAUSE, μ: SHORT DURATION PAUSE (SUCH AS THE BREATH TAKEN BETWEEN EACH WORD), ω: MEDIUM DURATION PAUSE, α: LONG DURATION PAUSE, ‿: CONTINUATION, •: NOT PRONOUNCED

| Phonetic | Orthographic | Phonetic | Orthographic | Phonetic | Orthographic |
|---|---|---|---|---|---|
| /ma‿ • smik/ | مَا اسمِك | /ʔat:amarΦ/ | التَّمَر | /bim • aː/ | بِمَا |
| /ʔinbaʕaθa/ | انبَعَثَ<br>انبَعَثَ | /bariː?/ | بَرِيء<br>بَرِيء | /masʕuːlin/ | مَسؤُولٍ |
| /min μ baʕdi/ | مِن بَعدٍ | /bima/ | بِمَ | /ʔum:i/ | أمِّ |
| /bimaː/ | بِما | /wa • stasˤlaħa/ | وَاستَصلَحَ<br>وَاستَصلَحَ | /katabaː/ | كَتَبَا |

*1) Evaluation of the words and phrases:* A rich listing of valid diacritized words and phrases was produced to test the edge cases. The following words were a test bed for Harakat: vowels and non-contextual graphemes; phonemes and contextual graphemes; phonemes; and words may have multiple pronunciations. Words and short sentences were then chosen that contained characters that had varied context pronunciation, specifically, the definite article (ال), Harakat (ـَ ـِ ـُ), Tanween (ـً ـٍ ـٌ), ta' marbutah (ة), alif (ا), lam (ل), waw (و), and ya (ي). Table XII gives the comprehensive evaluation of the phonotizer to ensure that all edge cases were tested. A comparison of the system outputs with the IPA transcription by a language specialist revealed the transducer's accuracy and coverage. Notice that phonotizer output symbols, such as zero duration pauses and deletions, were not present in the transcription. Table III presents the system output of various inputs and is a subset of Table XII in Appendix B.

*2) Tashkeela corpus evaluation:* Table XIII in the evaluation appendix details the system results for a random sample of sentences from Tashkeela corpus that are fully diacritized MSA texts taken from various internet sources, such as Al Jazeera and al-kalema.org. Numbers, foreign words, misspellings, partially diacritized text, and colloquial dialects were out of the system scope.

The phonetizer output was compared with the output from a native Arabic speaker trained in reading IPA and MSA, who provided an IPA transcription of the texts as this was not provided in the Tashkeela corpus. Table XIII indicates that the proposed system performed accurately on a large variety of texts.

Differences between the proposed system's output and the expected transcription were due to missing diacritization, the lack of Mad character in a word, and loan words that had a lack of diacritization and sometimes irregular pronunciation. Detailed explanations for these specific differences are shown in Table XIII in Appendix B.

*3) Wikipedia sentence evaluation:* Table XIV in Appendix B compares the phonetizer output and the IPA transcription for the selected Wikipedia examples [4] [5]. These examples were used because there were no corpora available that contained both orthographic texts with phonetic transcriptions. As can be seen, no deviations were found between the two.

## IV. MORPHOLOGICAL TRANSDUCER (FSAM)

A morphological FST was designed that generates/synthesizes words in the forward direction from morphemes and in the backward direction, decomposes a word into its morphemes. The morphologizer concatenates morphemes that are prefixes, stems, or suffixes and also works on a templatic level when morphemes are interdigitized patterns and roots that make a stem and are meaning-bearing units. Interdigitation refers to the insertion of root components into the corresponding placeholders in the pattern.

In contrast to the existing approaches outlined in Appendix A, the proposed morphologizer is both concatenative and templatic, with the FST used instead of tabulation for the con-

---

[4]https://en.wikipedia.org/wiki/Varieties_of_Arabic#Examples_of_major_regional_differences
[5]https://en.wikipedia.org/wiki/Arabic_phonology

TABLE III. CONTEXT-DEPENDENT PRONUNCIATION EXAMPLES FOR VARIOUS RULE CATEGORIES AND THE EXPECTED (IPA) VS OUTPUT

| Test phonetic transcription: characters for which the pronunciation is affected by context are colored red. Φ: zero duration pause, μ: short duration pause, ω: medium duration pause, α: long duration pause ⌣ : continuation, • : not pronounced | | | | | |
|---|---|---|---|---|---|
| Phrase | IPA | Output(s) | Phrase | IPA | Output(s) |
| **Definite Article (ال)** | | | **Alif mad (آ)** | | |
| إِلَى الِاغْتِرَافِ | ʔila⌣lʔiʕtira:fi | ʔil • a⌣lʔiʕΦtira:fi | آبَاز | ʔa:ba:r | ʔa:ba:rΦ |
| **Madd (آ)** | | | **Alif (ا)** | | |
| هَٰذَا | ha:ða: | ha:ð • a: | وَاقْرَأْ | waqraʔ | wa • qΦraʔ μ |
| **Alif maqsurah (ى)** | | | **Harakat (ـَـِ)** | | |
| هُدَى القُلُوب | hudȧ⌣lqulu:b | hud • a⌣lqulu:bΦ | حِينَ | ħi:na | ħi:na |
| **Hamza and her sisters (ء, أ, إ, ؤ, ئ)** | | | **Waw (و) and Ya (ي)** | | |
| فِئَة | fiʔah | fiʔah | مَوز | mawz | mawz |
| **Ta' Marbutah (ة)** | | | **Tanween (ـًـٍ)** | | |
| الْمَدْرَسَـةْ. | ʔalmadrasah ‖ | ʔalmadΦrasahΦ α | أَيٌّ | ʔaj:in | ʔaj:in |



Fig. 2. Arabic word morpheme breakdown. A word is a concatenation of a prefix, stem, and suffix (concatenative). A stem is a meaning-bearing unit that can be further decomposed into its root and pattern (templatic). The root gives the core meaning and the pattern provides the part of speech (POS, category) and other linguistic properties, such as number, tense, and gender. This image uses the Buckwalter transliteration scheme (www.qamus.org/transliteration.htm).

catenative rules. The proposed FST has a single level rather than two levels, into which patterns and roots are input. The morphologizer has a distinct rewrite rules layer to interdigitate the patterns and roots and concatenate the affixes and stems.

Fig. 3 illustrates the proposed FST's inputs and outputs using the word example fasamiEahaA (so he heard her), which was decomposed to the prefix fa (so), the stem samiEa (he heard), and the suffix haA (her), and the stem was further analyzed to the root s m E (to hear) and the pattern faEila (he did). The forward direction FST analysis produced the morphemes and the linguistic features, such as gender, and in the backward direction, generated a word.

The FST works as an acceptor, a synthesizer, and an analyzer and uses the same architecture for both diacritized and undiacritized words. The diacritized version has diacritized morphemes and the undiacritized version has undiacritized morphemes. The morphemes and allowable combinations were derived from multiple linguistic sources (7; 8; 9).

State-of-the-art concatenative morphological formalism comprises three components: lexical automaton, morphotactic rules, and rewrite rules. FSAs are constructed to represent prefixes, stems, and suffixes, which are concatenated with markers based on morphotactic rules that specify valid combinations to separate them into lexical forms, that is, the morphotactic (governing the morphemic combinations, which are meaning-bearing units) and orthographic (spelling) rules are programmed into the FST. The orthographic changes that need to be made to the lexical form to yield the surface form (word) that incorporates contextual mapping are coded using rewrite rules in the FST.

The automaton utilizes morphotactic MSA grammatical rules that govern the allowable affixes and stem concatenations, and the Arabic grammar licit templatic morphological pattern and root combinations, which ensures that there are no invalid words. The proposed architecture incorporates roots and a wide variety of patterns, thereby generating a rich set of valid forms and an average of around 28 analyses per undiacritic word, which compares favorably to the table-based unidirectional universal machines in leading morphologizers that only provide a single analysis and do not have any root-based generation capabilities.

FSAM can be used as a forward direction generator and as a backward direction analyzer for both diacritic and undiacritic words. Therefore, finite-state machines (FSM's) benefits are its unified architecture, its bidirectionality, and its ability to hard wire patterns, which allows for the synthesis, analysis, and diacritization of words without the need for a lookup table.

The generator input is a root that can be either a pattern, an affix, or "print lower-words," and the output is all licit root, pattern, and affix combinations. A word that cannot be decomposed into a pattern and root is a fixed word, such as Washington, which is represented by the root being recognized as a fixed word without affixes and with the pattern being the identity.

The analyzer input is a word and the output is valid alternative morpheme decompositions (prefix, root, and suffix), patterns, parts-of-speech (category), and morphosyntactic features such as number and gender.

FSAM is a composite of three main automata layers, as

analyzer
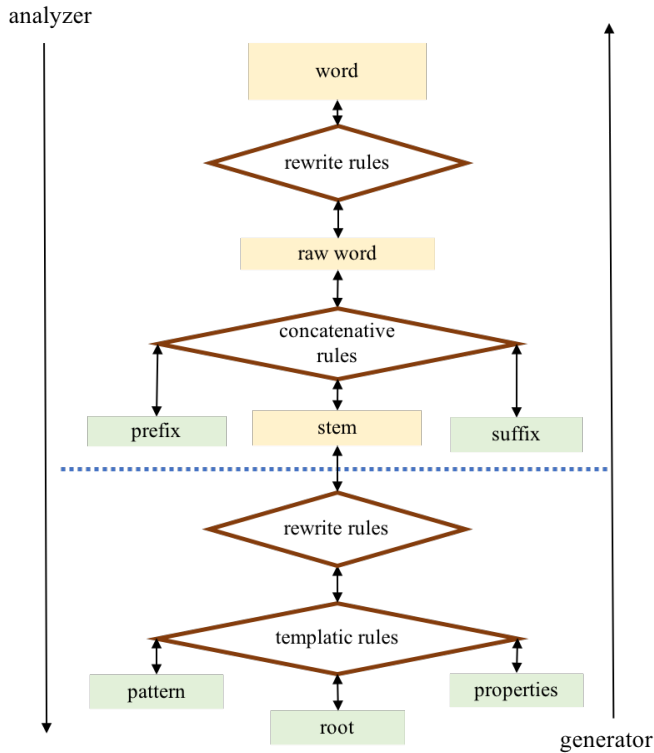


Fig. 3. Architecture for the bidirectional Finite-State Machine based morphological system. The top portion is the rule-based concatenative morphologizer and the bottom portion is the rule-based templatic morphologizer that produces the root, morphological pattern, and properties, such as the category (PoS) and the morphophonemic features. All of these are optional inputs in the generation (synthesis) direction.

shown in Fig. 3: (1) a templatic rule-based automaton that generates the pattern and root combinations into a word; (2) a concatenative rule-based automaton that generates prefix-stem-suffix combinations into a word; and (3) a rewrite rule transducer that applies orthographic and morphophonemic rules to the raw words.

### A. Stem Vocabulary Coverage

Stem vocabulary is synthesized in the transducer using a "print lower-words" command, from which a full list of stems is produced, all of which are valid words. The focus is on the stems (base words) rather than the words because of the large vocabulary that arises from additional prefix and suffix combinations. Table VI of Appendix B shows the related statistics.

When the undiacritized stem vocabulary was compared to the undiacritized words in the Tashkeela corpus, an overlap of 88,784 stems was found between the generated FSAM stems and the Tashkeela words, which contrasted favorably (six times more) with the 14,951 stem overlaps between MADAMIRA and the Tashkeela corpus.

### B. Expanding Coverage

Based on the compiled morpheme, the morphological automata strictly enforce the allowable prefixes, suffixes, and roots that can combine with a morphological pattern. As morpheme

combinations occur, they need to be added to the system sets. To allow for this expansion, a morphological automata version is constructed in which the restrictions on the roots, prefixes, and suffixes that combine with a pattern are removed but the precisely known hardwired patterns are retained.

An example of a pattern is فَعَلَ ('has done'), which could have the restricted sets وَ, فَ as roots ء ك ل, د ر س, ف ه م as prefixes, and هَا as suffixes. Therefore, if the word كَتَبَ is input into the proposed system, which does not have the root ك ت ب in the sets related to the فَعَلَ pattern, it can be analyzed using the open system and then added to the closed system, which only allows valid words to be analyzed, to improve the coverage.

If a trilateral pattern is allowed to correspond to any three-letter root, there is an unrestricted subsystem that allows valid words to be analyzed and the list of roots in the restricted system to be expanded. However, as this subsystem also admits many invalid words, it can only be used by a language specialist to expand the morpheme list.

### C. Evaluation

Different data sets and sources were employed to evaluate the various system parts. As detailed in Appendix B, to ensure there were no invalid or dialectal words that ignored the OOV and punctuation, a gold standard treebank was developed from the intersection of the PADT UD treebank[6] and the Tashkeela[7] corpus to test the morphologizer generation and analysis (synthesis) tasks for both the undiacritic and diacritic words.

The FSAM and FSAD results were compared to the leading Arabic morphologizer, MADAMIRA, which is a concatenative morphological analyzer that uses a Penn Arabic treebank as part of its training set and overlaps with the UD PADT. MADAMIRA(10) is a combination of the MADA (Morphological Analysis and Disambiguation of Arabic), which was built based on the SAMA (Standard Arabic Morphological Analyzer) and AMIRA (a morphological system for colloquial Egyptian Arabic). Different from MADAMIRA, FSAM and FSAD's rule-based system conducts an MSA templatic morphological analysis that yields a root and pattern, generation, and diacritization.

*1) Synthesizer evaluation:* FSAM synthesizes words in two ways: 1) it inputs the prefix-root-suffix to the system and outputs all words resulting from the many pattern and root combinations; and, 2) it issues a "print lower-words" command to the transducer to synthesize all stems that are valid pattern and root combinations or all words that are valid pattern, root, prefix, and suffix combinations. FSAM synthesizes the word vocabulary corresponding to the gold standard by inputting the root, prefix, and suffix combinations, which are decompositions of the gold standard words in the treebank. Consequently, the vocabulary is larger than the gold standard because of the additional patterns applicable to the prefix-root-suffix combinations. Table IX in the appendix illustrates the tremendous effect that the patterns have.

To evaluate the root generation ability, the root provided by the gold standard and the prefix and suffix provided by the gold standard word segmentation were used to generate possible

---

[6]https://github.com/UniversalDependencies/UD_Arabic-PADT
[7]https://sourceforge.net/projects/tashkeela/

Table IV. FSAM-generated Words from the Gold Standard Roots. The 'generated' Column Shows the Percentage of Roots the Model Generated from the Words; for example, Root لك is not Considered a Root in Arabic, and Therefore, no Words were Yielded. The 'correct' Column is the Percentage of FSAM-generated Words that Matched the Gold Standard.

### Generated/Synthesized Words from Roots

| UNDIAC | generated | correct |
|---|---|---|
| verb | 94.96 | 100 |
| tool word | 90.71 | 100 |
| noun | 91.71 | 100 |
| proper name | 91.28 | 100 |
| noun+verb | 92.48 | 100 |
| all | 91.89 | 100 |

words from the prefix, root, pattern, and suffix combinations. Table IV shows that 100% accuracy and 92% coverage were achieved when generating words from the root and its prefix and suffix.

*2) Analyzer evaluation using the gold standard:* The analyzer input is a word and the FSAM output is the root, pattern, category, or other linguistic information, such as number, gender, case, definiteness, and aspect. As the MADAMIRA output does not include the root or pattern, MADAMIRA was run in analysis-only mode.

A full analyzer evaluation should only be conducted against a gold standard reference. The Tashkeela corpus, however, is only a collection of morphologically valid Arabic words, whereas the gold standard treebank has root, category, and other linguistic information. For the undiacritized evaluation, all treebank words were input into the analyzer and matched against the analysis. The gold standard no OOV treebank was then used to evaluate the systems. Both systems had around 99% accuracy when computing gender, definiteness, person, case, aspect, and voice; however, the FSAM performed well for mood (99.7% vs 93%) and number (97.8% vs 90.5%) and was able to determine the root correctly about 92% of the time. Appendix B provides more details on the FSAM evaluation.

The advantage of the proposed system is that it can extract the word roots and patterns, that is, it can provide a shallow analysis of a word based on the pattern without needing to refer to a table of stems and their properties. Both systems' properties could produce the category, case, gender, mood, definiteness, number, person, voice, and aspect.

*3) Analyzer coverage evaluation:* The model coverage was evaluated by computing the percentage of analyzed words using a large corpus (Tashkeela). The FSAM analyzed 81.83% of the undiacritized words in the Tashkeela corpus and analyzed 82.24% of the undiacritized words in MADAMIRA (in analyses-only mode and no backoff). The backoff mode in MADAMIRA was not used because it admits invalid words.

The reduced coverage was largely because of the invalid words in the corpus. Invalid words are words that are misspelled, not words in the Arabic language, or a concatenation of words. Examples of words that could not be analyzed by both systems and were deemed invalid were شرنبلالي, السنبوسك , فوشيكوس, and words that were not separated by

whitespace and were considered to be one word (the dash (-) indicates where the words should be separated), such as : عباس-الفواحش,بالليل-والإباحة ,المصلين-والوجه,العدو-عليكم, الشعثاء-في, السدي-وخرج, الأواه-الذي, المسلمين-حال, وغيرها-وإني, مالك-والشافعي, المساجد-إلا, فأخبرني-محمد, يعني-البينات, عصير-والوجه, قوله-وهذا, سفيان-أن, أول-احتباسها

## V. Diacritic Transducer (FSAD)

As illustrated in Fig. 5, the system's diacritizer was developed using diacritized fixed words, the prefix and suffix listing for the simple diacritizer, and the diacritized MSA patterns for the pattern-based diacritizer. The simple diacritizer was used for the fixed words and affixes because they did not follow any pattern.

The diacritizer was designed in the forward direction, in which diacritics were inserted. The FST for the fixed words and affixes is a table that maps between the diacritized and undiacritized versions. The model used for the pattern-based words was an insertion FST that inserted diacritics into an undiacritic pattern to create the diacritic counter parts; for example, [8] $\Omega\Gamma\Lambda \rightleftharpoons \Omega a\Gamma a\Lambda a, \Omega a\Gamma{\sim}a\Lambda a, \Omega a\Gamma i\Lambda a, \Omega u\Gamma i\Lambda a$, where $\Omega$, $\Gamma$, and $\Lambda$ were placeholders for the root.
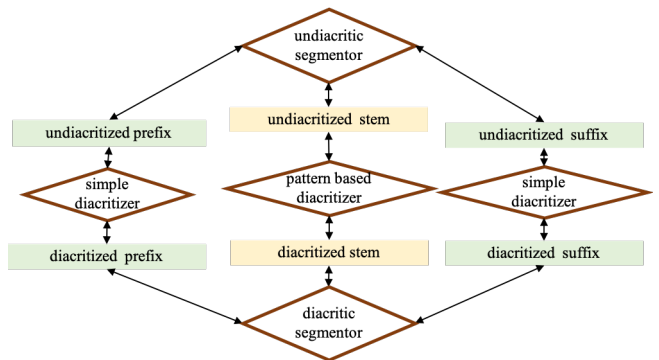


Fig. 4. Architecture for the finite-state machine-based diacritizer. The downward (forward) direction outputs diacritized words from an input undiacritized word. The segmenter decomposes the word into its prefix-stem-suffix. The pattern-based diacritizer inserts the diacritics into an undiacritized pattern to produce corresponding diacritized patterns; for example, فعل ⇌ فِعِل, فُعِل, فَعَل. To diacritize the stem using the pattern diacritizer, the stem is matched with the corresponding undiacritized pattern to produce the diacritic stem. The simple diacritizer inserts the diacritics directly into the undiacritized affix.

The segmenter decomposes a word into its prefix-stem-suffix components for which the stem could be a pattern-based word or a fixed word. After the word components are diacritized, they are then concatenated to form the diacritic word. The system diacritizer is illustrated in Fig. 4. A sample input and output(s) to this system is ودرسها ⇌ وَدَرَسَهَا, وَدَرَّسَهَا.

The diacritizer was evaluated by selecting all undiacritized words in the gold standard treebank, passing them into the diacritizer, and checking the output against the diacritized word contained in Vform. The diacritizer output was evaluated according to standard Arabic spelling rules. Note that the gold

---

[8]Please note we are using Buckwalter transliteration when not using Arabic script: http://www.qamus.org/transliteration.htm

standard meets these standards with some exceptions that are only apparent upon visual inspection.

TABLE V. DIACRITIZATION ACCURACY FOR THE TREEBANK. THE PATTERN-BASED MODEL HAD SIGNIFICANTLY HIGHER ACCURACY

| Word | FSAD | MADAMIRA |
|------|------|----------|
| verb | 85.91 | 80.99 |
| proper name | 82.46 | 50.78 |
| noun | 83.67 | 53.49 |
| noun+verb | 84.01 | 58.76 |
| toolword | 83.34 | 53.43 |
| all | **83.65** | 58.59 |

The evaluation in Table V indicates that the FSAD performed better than the MADAMIRA for the full diacritization (84% vs 59%) because the FSAD does not learn the diacritization from the corpus but deduces it based on the patterns that exist in the Arabic language, whereas MADAMIRA trains its model on corpora and, therefore, has a more partial diacritization.

Because the gold standard has spelling inconsistencies between the diacritized and undiacritized words, the performance was reduced, as shown in Table V. The following examples had the following (inconsistencies), which could have had a significant effect on the evaluation.

- Using ى instead of ي (e.g., مدنى ⇐ مَدَنِـيٌّ , فى ⇐ فِـي ,
  (أَلفِـيَ ⇐ ألفى, حَوَالَـي ⇐ حوالـى)

- Using ا instead of آ (e.g., اب ⇐ آبَ, الاستانة ⇐ الآسِتانَةِ,
  (آخَرُ ⇐ اخر)

- Using ا instead of إ (e.g., الى ⇐ إلَى, اطلاق ⇐ إطلاقِ,
  (إشَارَةِ ⇐ اشارة)

## VI. CONCLUSION

This study designed and constructed a bidirectional integrated phonetizer, morphologizer, and diacritizer system (FSPMD), the coverage of which could be increased by adding foreign words and special morpheme roots with the associated rules in the appropriate order. The FSPMD structure could be mimicked to build morpho-phonological systems for rule-based languages, such as Hebrew and Aramaic. The system could also be used in many language technologies, such as speech recognition, information retrieval, and spelling and grammar checkers, without the need to incorporate large tabulations that increase system complexity, out-of-vocabulary words, and perplexity. The system could also be used to construct a semantic analyzer and word translator and as part of a suprasegmental phonologizer that applies syllables, stress, and intonation rules, which would make it useful for text-to-speech technologies. On the text side, the syntactic parser has greater scope than most FSMs, which means it can deal with long-distance rules beyond formal languages, such as context-sensitive grammar or tree adjoining grammar.

## REFERENCES

[1] D. Jurafsky and J. H. Martin, Eds., *Speech and Language Processing: An Introduction to Natural Language Processing, Computational Linguistics, and Speech Recognition*, 2020.

[2] F. Seifart, ``Orthography development,'' *Essentials of language documentation*, pp. 275--299, 2006.

[3] R. Hetzron, Ed., *The Semitic Languages*. Routledge, 1997.

[4] M. Hulden, ``Foma: a finite-state compiler and library,'' in *Proceedings of the Demonstrations Session at EACL 2009*, 2009, pp. 29--32.

[5] N. Halabi, ``Modern standard arabic phonetics for speech synthesis,'' Ph.D. dissertation, University of Southampton, 2016.

[6] T. Zerrouki and A. Balla, ``Tashkeela: Novel corpus of arabic vocalized texts, data for auto-diacritization systems,'' *Data in Brief*, vol. 11, pp. 147 -- 151, 2017.

[7] A. Dahdah and G. M. Abdulmassih, *A dictionary of Arabic grammar in charts and tables*. Librairie du Liban, 1981.

[8] M. b. A. B. Al-Razi, ``Mukhtar al-sihah,'' *Beirut: Dar al-Namudzajiyah*, 1999.

[9] A. El-Dahdah, E. Matar, and G. M. Abdul-Massih, ``majam qawaaid al-arabiiat al-aalamiiat (a dictionary of universal arabic grammar)/معجم قواعد العربية العالمية,'' 1990.

[10] A. Pasha, M. Al-Badrashiny, M. T. Diab, A. El Kholy, R. Eskander, N. Habash, M. Pooleery, O. Rambow, and R. Roth, ``Madamira: A fast, comprehensive tool for morphological analysis and disambiguation of arabic.'' in *Lrec*, vol. 14, no. 2014, 2014, pp. 1094--1101.

[11] K. R. Beesley, ``Finite-state morphological analysis and generation of arabic at xerox research: Status and plans in 2001,'' in *ACL Workshop on Arabic Language Processing: Status and Perspective*, vol. 1. Citeseer, 2001, pp. 1--8.

[12] N. Y. Habash and O. C. Rambow, ``Magead: A morphological analyzer and generator for the arabic dialects,'' 2006.

[13] K. Darwish, M. Diab, and N. Habash, ``Proceedings of the acl workshop on computational approaches to semitic languages,'' in *Proceedings of the ACL Workshop on Computational Approaches to Semitic Languages*, 2005.

[14] M. Attia, P. Pecina, A. Toral, L. Tounsi, and J. van Genabith, ``An open-source finite state morphological transducer for modern standard arabic,'' in *Proceedings of the 9th International Workshop on Finite State Methods and Natural Language Processing*, 2011, pp. 125--133.

[15] K. Darwish, ``Building a shallow arabic morphological analyser in one day,'' in *Proceedings of the ACL-02 workshop on Computational approaches to semitic languages*, 2002.

[16] T. Buckwalter, ``Buckwalter arabic morphological analyzer version 1.0,'' *Linguistic Data Consortium, University of Pennsylvania*, 2002.

[17] D. Graff, M. Maamouri, B. Bouziri, S. Krouna, S. Kulick, and T. Buckwalter, ``Standard arabic morphological analyzer (sama),'' *Linguistic Data Consortium LDC2009E73*, 2010.

[18] O. Smrz, ``Elixirfm--implementation of functional arabic morphology,'' in *Proceedings of the 2007 workshop on computational approaches to Semitic languages: common issues and resources*, 2007, pp. 1--8.

[19] R. Roth, O. Rambow, N. Y. Habash, M. Diab, and C. Rudin, ``Arabic morphological tagging, diacritization, and lemmatization using lexeme models and feature ranking,'' 2008.

[20] E. L. Antworth, ``Pc-kimmo: a two-level processor for morphological analysis,'' *Summer Institute of Linguistics*,

1990.

[21] L. Karttunen, *Finite-state lexicon compiler*. Xerox Corporation, Palo Alto Research Center, 1993.

[22] G. Kiraz, ``Multi-tape two-level morphology: a case study in semitic non-linear morphology,'' *arXiv preprint cmp-lg/9407023*, 1994.

[23] M. Mohri, F. Pereira, and M. Riley, ``Weighted finite-state transducers in speech recognition,'' *Computer Speech Language*, vol. 16, no. 1, pp. 69--88, 2002. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0885230801901846

[24] M. T. Diab, ``Second generation amira tools for arabic processing : Fast and robust tokenization , pos tagging , and base phrase chunking,'' 2009.

[25] A. A. Al-Nassir, ``Sibawayh the phonologist: A critical study of the phonetic and phonological theory of sibawayh as presented in his treatise? al kitab?'' Ph.D. dissertation, University of York, 1985.

[26] Y. A. El-Imam, ``Phonetization of arabic: rules and algorithms,'' *Computer Speech & Language*, vol. 18, no. 4, pp. 339--373, 2004.

[27] F. Biadsy, N. Habash, and J. Hirschberg, ``Improving the arabic pronunciation dictionary for phone and word recognition with linguistically-based pronunciation rules,'' in *Proceedings of human language technologies: The 2009 annual conference of the North American chapter of the association for computational linguistics*, 2009, pp. 397--405.

[28] A. Ramsay, I. Alsharhan, and H. Ahmed, ``Generation of a phonetic transcription for modern standard arabic: A knowledge-based model,'' *Computer Speech & Language*, vol. 28, no. 4, pp. 959--978, 2014.

[29] M. Maamouri, A. Bies, T. Buckwalter, and W. Mekki, ``The penn arabic treebank: Building a large-scale annotated arabic corpus,'' in *NEMLAR conference on Arabic language resources and tools*, vol. 27. Cairo, 2004, pp. 466--467.

[30] J. Åkesson, ``Arabic morphology and phonology: Based on the marāḥ al-arwāḥ by aḥmad b.ʿaī b. mas ʿūd,'' in *Arabic Morphology and Phonology*. Brill, 2017.

[31] A. A. S. Farghaly, ``Arabic computational linguistics,'' *(No Title)*, 2010.

[32] M. Sipser, *Introduction to the Theory of Computation*. Cengage Learning, 2012.

[33] R. M. Kaplan and M. Kay, ``Regular models of phonological rule systems,'' *Computational linguistics*, vol. 20, no. 3, pp. 331--378, 1994.

[34] K. Koskenniemi, ``Two-level morphology,'' Ph.D. dissertation, Ph. D. thesis, University of Helsinki, 1983.

[35] L. Karttunen *et al.*, ``Kimmo: a general morphological processor,'' in *Texas Linguistic Forum*, vol. 22. Texas, USA, 1983, pp. 163--186.

[36] J. Bear, ``A morphological recognizer with syntactic and phonological rules,'' in *COLING*, vol. 86, no. 10.3115, 1986, pp. 991 365--991 445.

[37] ------, ``Morphology with two-level rules and negative rule features,'' in *Coling Budapest 1988 Volume 1: International Conference on Computational Linguistics*, 1988.

[38] A. W. Black, G. Ritchie, S. Pulman, and G. Russell, ``Formalisms for morphographemic description,'' in *Third Conference of the European Chapter of the Association for Computational Linguistics*, 1987.

[39] K. Beesley, T. Buckwalter, and S. Newton, ``Two-level finite-state analysis of arabic morphology,'' in *Proceedings of the Seminar on Bilingual Computing in Arabic and English*, 1989, pp. 6--7.

[40] H. Trost, ``The application of two-level morphology to non-concatenative german morphology,'' 1990.

[41] G. D. Ritchie, *Computational morphology: practical mechanisms for the English lexicon*. MIT press, 1992.

[42] E. L. Antworth, ``Morphological parsing with a unification-based word grammar,'' in *Proceedings of the North Texas Natural Language Processing Workshop*. Citeseer, 1994, pp. 24--32.

[43] H. Ruessink, *Two-level formalisms*. Katholieke Universiteit, 1989.

[44] D. Carter, ``Rapid development of morphological descriptions for full language processing systems,'' *arXiv preprint cmp-lg/9502006*, 1995.

[45] E. Grimley-Evans, G. A. Kiraz, and S. G. Pulman, ``Compiling a partition-based two-level formalism,'' *arXiv preprint cmp-lg/9605001*, 1996.

[46] S. Bird, E. Klein, and E. Loper, *Natural language processing with Python: analyzing text with the natural language toolkit*. " O'Reilly Media, Inc.", 2009.

[47] C. D. Johnson, *Formal aspects of phonological description*. Walter de Gruyter GmbH & Co KG, 2019, vol. 3.

[48] K. R. Beesley and L. Karttunen, ``Finite-state morphology: Xerox tools and techniques,'' *CSLI, Stanford*, pp. 359--375, 2003.

[49] S. Bird and T. M. Ellison, ``One-level phonology: Autosegmental representations and rules as finite automata,'' *Computational Linguistics*, vol. 20, no. 1, pp. 55--90, 1994.

[50] K. R. Beesley and L. Karttunen, ``Finite-state non-concatenative morphotactics,'' *arXiv preprint cs/0006044*, 2000.

[51] J. J. McCarthy, ``A prosodic theory of nonconcatenative morphology,'' *Linguistic inquiry*, vol. 12, no. 3, pp. 373--418, 1981.

[52] M. Kay, ``Nonconcatenative finite-state morphology,'' in *Third Conference of the European Chapter of the Association for Computational Linguistics*, 1987.

[53] J. A. Goldsmith, *Autosegmental and metrical phonology*. Basil Blackwell Cambridge, 1990, vol. 1.

[54] J. McCarthy and A. Prince, ``Prosodic morphology and templatic morphology,'' in *Perspectives on Arabic linguistics II: papers from the second annual symposium on Arabic linguistics*. John Benjamins Pub. Co. Amsterdam, 1990, pp. 1--54.

[55] J. J. McCarthy and A. Prince, ``Generalized alignment,'' in *Yearbook of morphology 1993*. Springer, 1993, pp. 79--153.

[56] L. Kataja and K. Koskenniemi, ``Finite-state description of semitic morphology: A case study of ancient accadian,'' in *Coling Budapest 1988 Volume 1: International Conference on Computational Linguistics*, 1988.

[57] K. Beesley, ``Finite-state description of arabic morphology,'' in *Proceedings of the Second Cambridge Conference: Bilingual Computing in Arabic and English*, 1990, pp. 5--7.

[58] K. R. Beesley, ``Computer analysis of arabic morphology: A two-level approach with detours,'' in *Perspectives on Arabic Linguistics III: Papers from the Third Annual*

*Symposium on Arabic Linguistics.* John Benjamin's Publishing Company Amsterdam, 1991, pp. 155--172.

[59] ------, ``Arabic finite-state morphological analysis and generation,'' in *COLING 1996 Volume 1: The 16th International Conference on Computational Linguistics*, 1996.

[60] R. W. Sproat, *Morphology and computation*. MIT press, 1992.

[61] S. G. Pulman and M. R. Hepple, ``A feature-based formalism for two-level phonology: a description and implementation,'' *Computer Speech & Language*, vol. 7, no. 4, pp. 333--358, 1993.

[62] A. Narayanan and L. Hashem, ``On abstract finite-state morphology,'' in *Conference of the European Chapter of the Association for Computational Linguistics*, 1993.

[63] K. R. Beesley, ``Arabic morphology using only finite-state operations,'' in *SEMITIC@COLING*, 1998.

[64] G. A. Kiraz, ``Multitiered nonlinear morphology using multitape finite automata: a case study on syriac and arabic,'' *Computational Linguistics*, vol. 26, pp. 77--105, 2000.

[65] A. Kornai, ``Formal phonology,'' 2018.

[66] B. Wiebe, ``Modelling autosegmental phonology with multi-tape finite state transducers,'' 1992.

## Appendix A
## Related Work

### A. Arabic Morphologizers

The most significant morphological analyzers are those that utilize finite-state transducer formalism, such as Xerox(11), the morphological analyzer and generator for the Arabic dialects (MAGEAD)(12; 13) , and the Arabic Computer Lexicon (AraComLex)(14), and those that utilize a tabular approach, such as Darweesh(15), the Buckwalter Morphological Analyzer for Arabic (BAMA)(16), the Standard Arabic Morphological Analyzer (SAMA)(17), ElixirFM(18), a high-level implementation of functional Arabic morphology, Morphological Analysis and Disambiguation of Arabic (MADA)(19), and MADAMIRA(10).

The Xerox Arabic morphologizers, which are bidirectional morphologizers that take diacritized or undiacritized words as the input and compute the prefix, pattern, root, and suffix, were based on a finite-state transducer (FST) and utilize grammar rules rather than listing the stems. For example, Beesley's(11) Xerox finite-state morphological analyzer, which was built on finite-state transducer advancements to handle morphology and uses Xerox finite-state language modeling tools, is rule-based and has a large coverage. Because the Xerox finite-state morphological analyzer adopts a root-and-pattern approach, it can generate all possible morphological features for each word; 4,930 roots and 400 patterns that generate 90,000 stems; can also reconstruct the vowel marks, and provides an English glossary for each word. The Xerox finite-state morphological analyzer was based on the ALPNET developed earlier by Beesley and Buckwalter, which was founded on PC-KIMMO. This tool was constructed as two-level morphology by Antworth and Karttunen(20; 21).

The MAGEAD morphologizer system, which extended Kiraz's(22) work using AT&T's finite-state machine toolkit(23), decomposes an isolated diacritized word into prefix, pattern, root, and suffix and generates words from input morphemes, that is, it is a bidirectional morphologizer. MAGEAD also provides linguistic features, such as word class, in a hierarchical form; however, it is currently restricted to verbs. MAGEAD, which is based on a multitape finite-state transducer similar to the Xerox-based work of Beesley and Kiraz, has morphophonemic and orthographic rewrite rules that extend Kiraz's analysis by introducing a fifth tier: Tier 1: pattern and affixational morphemes; Tier 2: root; Tier 3: vocalism; Tier 4: phonological representation; and Tier 5: orthographic representation. In the generation direction, tiers 1 through 3 are always the input tiers, Tier 4 is first, an output tier and then, a subsequent input tier, and Tier 5 is always an output tier.

The AraComLex is an open-source data-driven Arabic morphologizer that utilizes a bidirectional FST and uses the lemma as its base form. As a lemma is a marked form of a word without affixes and is not inflected, it has shorter lexicons than stem-based methods and can benefit from generalized rules rather than listings. For Arabic, this is typically the perfective, 3rd person singular verbs or the singular indefinite form for nouns and adjectives. Other inflected forms are derived from the lemma using alteration rules, which is different from the root-based Xerox morphologizer and the stem-based BAMA/SAMA morphologizers.

Darwish's(15) tabular method is a morphological analyzer that uses automatically-derived rules and statistics from the "Build-Model" module in the morphologizer. This module takes a list of word-root pairs as the input, which allows it to extract a list of prefixes, suffixes, and stem templates. The probability of each item's occurrence in these lists is then used to generate the statistical rules. The Darwish Morphologizer has been found to have an 84% success rate(15). Its "Detect-Root" module extracts all possible roots for an input word by generating a prefix, suffix, and stem, removing the prefix and suffix from the stem, and matching the stem against the templates, with the resultant template (along with the stem) being used to determine the root.

The BAMA was first developed by Buckwalter and has since had three versions; BAMA[9] versions 1.0 and 2.0(16); and SAMA[10] 3.1.; all of which are available as source codes from LDC. The input and output are in transliterated Roman letters and the program is written in Perl.

SAMA's input is isolated words, that is, sentence context is not considered in the disambiguation. The input word may be either diacritized on undiacritized, with the output being all possible prefix, stem, and suffix combinations, that is, it is a stemmer rather than a deep morphologizer. As SAMA is non-bidirectional, words may not be generated from the prefix, stem, and suffix inputs. In addition to stemming, the BAMA/SAMA also provides a part of speech tag. Rather than incorporating grammatical rules, BAMA/SAMA uses manually entered lexicons and morphotactic rules as its tables, which makes it difficult to generalize and requires significant manual effort to scale. In addition to the tables that specify the allowable prefix, suffix, and stem set combinations, the lexicons also include prefix, suffix, and stem sets. BAMA 1.0 has 299 prefixes,

---

[9] https://catalog.ldc.upenn.edu/LDC2002L49, https://catalog.ldc.upenn.edu/LDC2004L02

[10] https://catalog.ldc.upenn.edu/LDC2010L01

618 suffixes, and 82158 stems, 1648 prefix-stem combinations, 1285 stem-suffix combinations, and 598 prefix-suffix combinations. SAMA 3.1 has 1328 prefixes, 945 suffixes, 79318 stems, 40654 stem categories, 2497 prefix-stem combinations, 1632 stem-suffix combinations, and 1180 prefix-suffix combinations. A simple Perl program uses these to segment a word into all possible prefix-stem-suffix set combinations. Although the BAMA/SAMA uses reasonably sized tables, it is quite efficient and compact.

ElixirFM uses SAMA resources and Haskell's functional morphology library to incorporate the interface between morphology and syntax and determine the morphophonemic patterns to identify the roots and templates for the SAMA lexical items. MADA (Morphological Analysis and Disambiguation for Arabic) uses Support Vector Machines to compute nineteen features; five for spelling variations and fourteen for morphological features, such as number, gender, case, and mood. MADAMIRA is a concatenative morphological analyzer that uses the Penn Arabic treebank as part of its training set. MADAMIRA (10) is a combination of the MADA, which was based on SAMA, and AMIRA (24), a morphological system for colloquial Egyptian Arabic).

### B. Arabic Phonetizers

Classical Arabic literature provides a rich set of pronunciation rules for classical Arabic(25). Recent publications provide pronunciation rules for modern Arabic that were extracted from traditional sources(26; 27). However, some rules that should be included have been excluded, others that should have been excluded because they relate to spelling have been incorporated, and the effect of text markers has been ignored, all of which have significant consequences on phonetization, which means that the pronunciation produced using these rules can have many errors.

In recent publications, gemination has been handled by doubling a singleton consonant or mapping into its singleton version, which is phonetically inaccurate as demonstrated by geminated plosives that have a single voice onset time and release. Similarly, a long vowel is dealt with by doubling its short version, whereas the spectral characteristics of a long vowel are noticeably different from its short vowel counterpart(**author?**) (5). Also, the rules related to Wasl characters (ب ف ك و) are ignored, even though they frequently occur. Four additional forms for (ء) (أ إ ؤ ئ), (آ), end of sentence vowels, mapping (ا) at the beginning of a sentence into a glottal stop, and the pronunciation of (ة) as /h/ at the end of the sentence are also not considered.(26) ignored short vowels at the end of a sentence by removing them and (آ), and(27) did not incorporate situations that require the mapping of (آ).

(28) used a rule-based two-level finite-state automata to develop an orthographic to allophonic mapping, with the first level being grapheme to grapheme changes such as deletion and duplication, and the second level being grapheme to phoneme changes. The allophonic changes are then applied to the phoneme level to produce an allophonic transcription and evaluate the system output on the diacritized words from the Penn Arabic treebank(29). While some of the problems in previous publications were resolved, duplication rather than gemination is employed and Sokoon is excluded from the rules when it uses

syllable structure to determine the pronunciation of waw, ya', and Alif Wasl. In addition, ta' marbutah is deleted rather than pronouncing it as /h/ at the end of an utterance.

<center>

APPENDIX B
FSPMD (SYSTEM) EVALUATION

</center>

### A. Reference Corpus for Evaluation

Tashkeela(6), PADT_UD treebank, and MADAMIRA(10) were used to evaluate and compare the performance of the developed morphology generator, analyzer, and diacritizer. Tashkeela, Wikipedia , and modern standard Arabic orthography to phoneme transcriptions as well as specific examples that highlighted edge cases were used to fully test the orthography to phoneme transcription system.

As FSAM performs generation, analysis, and diacritization tasks that cover both undiacritic and diacritic words, a corpus of diacritized Arabic was needed to evaluate the proposed system. Tashkeela is one of the few available corpora that satisfied our requirements as it is a collection of diacritized passages in Classical and modern standard Arabic. Further, as our system is a deep morphologizer that works at pattern and root levels, the PADT_UD treebank, which was built on the Prague Arabic Treebank (Hajic et al. 2004), was the only resource available for a granular generation and analysis evaluation because alternatives such as the Penn Arabic treebank (Maamouri et al. 2004) lack root information. The PADT_UD is the Universal Dependencies Prague Arabic Treebank of modern standard and colloquial Arabic that contains undiacritized words, with the analysis consisting of the root, the Vform (the diacritized word), gender, number, case, definite, voice, and others. The FSAM was compared with the MADAMIRA (in analysis-only mode), which is a concatenative morphologizer (a morphologizer that gives the features of the words such as number, gender, person, etc. but does not give the composition of the word in terms of its pattern and root) rather than a templatic morphologizer, which partially makes up for the absence of patterns and roots by utilizing the SAMA stem categories to provide some granular analysis.

*1) Fully diacritized text and corpus and treebank vocabulary:* The diacritized texts in the Tashkeela corpus were utilized to manually test the ability of our orthography to phonemic systems and to test the correctness of our model, IPA was used to transcribe the MSA fully diacritized sentences from Wikipedia.

The undiacritized and diacritized word vocabulary was computed in Tashkeela and PADT_UD. Table VI conveys the word statistics after the punctuation was removed.

*2) Gold sandard :* A gold standard was generated from the PADT_UD treebank as a reference for the evaluation of the analysis and generation capabilities. A gold standard must be free from punctuation, abbreviations (e.g., كم "km"), foreign words (e.g., واشنطن "Washington"), affixes (e.g., ال), and single-character graphemes (ت); which are not considered words in the Arabic language.

To eliminate words that were colloquial rather than modern standard Arabic, PADT_UD was intersected with Tashkeela, followed by the serial removal of affixes, single-character graphemes (letters), foreign words, and abbreviations. Table VI also details the statistics for the intersection between

TABLE VI. LEFT: DIACRITIZED VOCABULARY AND THE RESULTING UNDIACRITIZED WORDS IN EACH RESOURCE IGNORING PUNCTUATION. THE PADT_UD DIACRITIZED WORDS ARE THOSE LISTED AS VFORM (VOCALIZED FORM) IN ITS ANALYSIS OF UNDIACRITIZED WORDS. RIGHT: GOLD STANDARD TREEBANK IS THE INTERSECTION OF TASHKEELA AND THE PADT_UD FOLLOWED BY THE REMOVAL OF ISOLATED AFFIXES, LETTERS, FOREIGN WORDS, ABBREVIATIONS, AND ENTRIES WITH NO ANALYSIS (OOV)

| References Vocabulary | | | | | |
| --- | --- | --- | --- | --- | --- |
| | undiacritized | diacritized | | undiacritized | diacritized |
| Tashkeela | 481,611 | 982,922 | Intersection | 16,760 | 27,097 |
| PADT UD | 23,175 | 33,597 | Gold Standard | 16,469 | 26,772 |
| | | | Gold Standard - no OOV | 15,035 | 24,080 |

PADT_UD, Tashkeela, and the gold standard, which is the intersection that excludes affixes, foreign words (determined by Foreign = Yes in the PADT_UD analyses), and abbreviations (determined by Abbr = Yes in the PADT_UD analyses).

*3) Category correspondence:* There is a mismatch in groupings and terminologies between our system, PADT_UD, and MADAMIRA. As the proposed system is based on Arabic language constructs, it uses intrinsic categories; verb, noun, tool word, and proper name. The verbs and nouns are further classified as regular and irregular. In contrast, PADT_UD labels words according to the standard part-of-speech classification scheme in English, and MADAMIRA labels words according to stem classes in the underlying SAMA corpus.

TABLE VII. PADT_UD LABEL CORRESPONDENCE TO THE NOUN, VERB, TOOL WORD, AND PROPER NAME CATEGORIES, AND THE DIACRITIZED (DIAC) AND UNDIACRITIZED (UNDIAC) STATISTICS FOR EACH LABEL

| LABEL | CATEGORY | DIAC | UNDIAC |
| --- | --- | --- | --- |
| NOUN | noun proper name tool word | 14,405 | 8,424 |
| X | proper name tool word noun | 2,693 | 2,679 |
| VERB | verb | 4,603 | 3,551 |
| PART | tool word | 19 | 21 |
| CCONJ | tool word proper name | 83 | 49 |
| AUX | | 99 | 90 |
| PRON | tool word | 12 | 34 |
| ADV | tool word | 22 | 25 |
| DET | tool word | 34 | 37 |
| PROPN | proper name | 29 | 28 |
| ADJ | noun proper name | 5199 | 3587 |
| INTJ | noun tool word | 3 | 3 |
| ADP | tool word proper name noun | 94 | 105 |

A label can map onto more than one category. For instance, a noun in PADT_UD may be a noun, proper name, or tool word as it contains words such as ميراث (inheritance) "noun," دولار (dollar) "proper name," and كل (all) "tool word." Therefore, a word that is analyzed as a noun in PADT_UD and analyzed as a tool word in the proposed model is marked as a tool word and a match occurs.

Table VII details the correspondence between the

TABLE VIII. MADAMIRA LABEL CORRESPONDENCE TO THE NOUN, VERB, TOOL WORD, AND PROPER NAME CATEGORIES

| LABEL | CATEGORY | LABEL | CATEGORY | LABEL | CATEGORY |
| --- | --- | --- | --- | --- | --- |
| abbrev | proper name | noun quant | noun | part interrog | tool word |
| noun prop | proper name | noun num | noun | part neg | tool word |
| verb | verb | noun | noun | part restrict | tool word |
| verb pseudo | verb | adj | noun | part verb | tool word |
| adv | noun | adj comp | noun | part voc | tool word |
| adv interrog | noun | adj num | noun | prep | tool word |
| adv rel | noun | part | tool word | pron | tool word |
| conj | noun | part det | tool word | pron dem | tool word |
| conj sub | noun | part focus | tool word | pron interrog | tool word |
| interj | noun | part fut | tool word | pron rel | tool word |

PADT_UD labels and the categories in the proposed system. Table VIII details the MADAMIRA label correspondence to the various categories: noun, verb, tool word, and proper name.

### B. FSAM analysis evaluation

Table XI compares the MADAMIRA's and FSAM's verb and noun analyses. Because of the overlap between Penn Arabic treebank, which is used as the MADAMIRA training corpus, and UD_PADT, the basis of our gold standard, MADAMIRA analyzed around 100% of the gold standard verbs and nouns, whereas FSAM analyzed around 84% of verbs and nouns.

MADAMIRA categorized the word correctly 100% of the time and FSAM categorized it correctly 97% of the time. Both systems had similar performances at around 99% accuracy when computing gender (99.5% vs 99.4%), definitiveness (99.3% vs 98.0%), person (98.2% vs 99.9%), case (99.4% vs 99.8%), aspect (99% vs 99.9%), and voice (99.8% vs 97.9%). FSAM performed better for mood (99.7% vs 93%) and number (97.8% vs 90.5%), and found the root with approximately 92% correctness.

### C. FSAP (Phonetic Transducer) Evaluation

The full range of examples to test FSAP are provided in Tables XII, XIII and XIV. In addition to the IPA non-phonemes of continuation (⌣), medium duration pause (|), and long duration pause (‖), we used zero duration pause, short duration pause, and not pronounced to more comprehensively reflect the morphophonetic relationships. These are the only expected differences between the Expected IPA and Output.

Table XII tests FSAP in all context dependent pronunciation environments, and as can be observed from the table, the system performs with 100% accuracy in those examples. Table XIII uses diacritized text from the Tashkeela corpus(6) to evaluate the system on diverse examples. Both tables XII and XIII don't have the expected IPA transcription as part of the corpus, so we used a language expert to transcribe the sentences into IPA to get the expected output.

TABLE IX. FSAM-GENERATED STEM VOCABULARY FOR EACH SUB-CATEGORY AND CATEGORY (TOP), AND MADAMIRA TABULATED STEM VOCABULARY (BOTTOM). *UNK MEANS THAT THE REFERENCE HAS NO STEM CATEGORIZATION. NO COUNTERPART IN MADAMIRA UNLESS THEIR REFERENCE - SAMA (HAS A LISTING OF STEMS) - IS DIRECTLY UTILIZED. NOUN, VERB, TOOL WORD, AND PROPER NAME CATEGORIES ARE BASED ON THE LABEL CORRESPONDENCE IN THE MADAMIRA REFERENCE TABLE SHOWN IN TABLE VIII. NOTE THAT A STEM HAS MULTIPLE LABELS IN THE REFERENCE

| Stem Vocabulary | | | | | |
|---|---|---|---|---|---|
| FSAM | undiacritized | diacritized | MADAMIRA | undiacritized | diacritized |
| regular verb | 579,522 | 1,882,047 | verb | 4,269 | 4,843 |
| irregular verb | 98,668 | 282,611 | noun | 11,950 | 12,763 |
| regular noun | 716,177 | 2,192,815 | toolword | 32 | 37 |
| irregular noun | 157,322 | 405,834 | proper name | 544 | 556 |
| toolword | 238 | 261 | UNK* | 8,849 | 11,897 |
| proper name | 7,681 | 8,352 | | | |
| TOTAL | 1,196,895 | 4,018,302 | TOTAL | 24,055 | 29,685 |

TABLE X. OVERLAP COUNT BETWEEN THE SYNTHESIZED UNDIACRITIZED STEMS AND THE GOLD STANDARD STEMS. THE INTERSECTION IS BETWEEN THE GOLD STANDARD AND SYNTHESIZED STEMS. MISSING IS THE SET GOLD STANDARD STEMS, THAT IS, THE SYNTHESIZED STEMS. AS THERE IS NO REFERENCE TO MADAMIRA FOR THE GENERATION OF STEMS FROM ROOTS, THE OVERLAP OF STEMS WAS CHECKED FROM THE UNDERLYING LISTING FOR THE GOLD STANDARD STEMS (8,536 STEMS)

| Generated Stem Overlap with the Gold Standard Stems | | |
|---|---|---|
| UNDIAC | FSAM | MADAMIRA |
| Intersection | 6,622 | 5,146 |
| Missing | 1,914 | 3,390 |
| Total | 8,536 | 8,536 |

TABLE XI. ANALYSIS ACCURACY FOR THE UNDIACRITIZED WORDS FOR THE GOLD STANDARD TREEBANK. ON THE LEFT IS FSAM (F) AND ON THE RIGHT IS MADAMIRA (M). TO PRODUCE ROOTS, THE MODEL OUTPERFORMED IN MOOD, NUMBER, AND VOICE PROPERTIES. MADAMIRA HAD ALMOST FULL COVERAGE OF THE GOLD REFERENCE BECAUSE OF THE OVERLAP BETWEEN THE TRAINING DATA AND THE REFERENCE

| Analysis Performance FSAM (F) vs MADAMIRA (M) | | | | | | |
|---|---|---|---|---|---|---|
| UNDIAC | verb | | noun | | noun+verb | |
| | F | M | F | M | F | M |
| analyzed | 94.9 | 99.9 | 83.4 | 99.8 | 83.8 | **99.8** |
| category | 99.0 | 99.9 | 96.8 | 100 | 97.0 | 100 |
| root | 94.0 | NA | 91.8 | NA | **92.3** | NA |
| case | - | - | 99.4 | 99.8 | 99.4 | 99.8 |
| gender | 99.4 | 100 | 99.6 | 98.9 | 99.5 | 99.4 |
| mood | 99.7 | 92.2 | - | - | **99.7** | 92.2 |
| definite | - | - | 99.3 | 98.0 | 99.3 | 98.0 |
| number | 99.3 | 100 | 97.4 | 88.0 | **97.8** | 90.3 |
| person | 98.2 | 99.9 | - | - | 98.2 | 99.9 |
| voice | 99.8 | 97.7 | - | - | 99.8 | 97.7 |
| aspect | 99.0 | 99.9 | - | - | 99.0 | 99.9 |

Table XIV tests the system on peer reviewed examples from Wikipedia [11] which contains the diacritized text and the corresponding expected IPA transcription.

---

[11]https://en.wikipedia.org/wiki/Varieties_of_Arabic# Typological_differences, https://en.wikipedia.org/wiki/Arabic_ phonology

TABLE XII. CONTEXT-DEPENDENT PRONUNCIATION EXAMPLES; EXPECTED VS OUTPUT

Test phonetic transcription: characters with pronunciation affected by context are colored red.
Φ: zero duration pause, μ: short duration pause, ω: medium duration pause, α: long duration pause, ⌣: continuation, •: not pronounced

| Phrase | Expected IPA | Output(s) | Phrase | Expected IPA | Output(s) |
|---|---|---|---|---|---|
| **Definite Article (الـ)** | | | **Alif maqsurah (ى)** | | |
| وَالقَهْرِ؛ | walqahr ‖ | walqahΦr • α | هُدَى القُلُوبُ | huda⌣lqulu:b | hud • a⌣lqulu:bΦ |
| القَهْرِ؛ | ʔalqahr ‖ | ʔalqahΦr • α | زُرْتُ هُدَى؛ | zurtu huda: ‖ | zurΦtu μ hud • a: α |
| وَالثَمَر | wat:amar | wa • t:amarΦ | لَمَـى بِنْتُ جَمِيلَة. | lama: bintun d͡ʒami:lah ‖ | lam • a: μ binΦtun μ d͡ʒami:lah α |
| الثَمَر | ʔat:amar | ʔat:amarΦ | **Alif mad (آ)** | | |
| هُذَا الكِتَابُ | ha:ða⌣lkita:bu | ha:ða⌣lkita:bu | آبَارُ | ʔa:ba:r | ʔa:ba:rΦ |
| دَرَسُوا الكِتَابَ | darasu⌣lkita:ba | darasu⌣lkita:ba | مَلآنْ | malʔa:n | malΦʔa:nΦ |
| فِي الكِتَابِ | fi⌣lkita:bi | fi⌣lkita:bi | **Madd (ˀ)** | | |
| إلَى الِاغتِرَافِ | ʔila⌣lʔiʕtira:fi | ʔil • a⌣lʔiʕΦtira:fi | هُذَا | ha:ða: | ha:ð • a: |
| **Hamza and her sisters (ء، أ، إ، ؤ، ئ)** | | | **Alif (ا)** | | |
| المَسَاء | ʔalmasa:ʔ | ʔalmasa:ʔ | وَاقرَأ | waqraʔ | wa • qΦraʔ μ |
| مَفْرُوءَةٍ؛ | maqru:ʔah ‖ | maqΦru:ʔah α | إقرَأ؛ | ʔiqraʔ ‖ | ʔiqΦraʔ α |
| بَرِيء | bari:ʔ | bari:ʔ | البَـابِ؛ | ʔalba:b ‖ | ʔalba:b α |
| أكَل | ʔakal | ʔakal | كَتَبُوا | katabu: | katabu: |
| أُكِل | ʔukil | ʔukil | مَا اِسْمُك؟ | ma⌣smuk ‖ | ma⌣ • sΦmuk α |
| ظَأطَأ | tˤaʔtˤaʔa | liʔan:a | كَرِيمًا | kari:man | kari:man |
| لأَنَّ | liʔan:a | liʔan:a | كَرِيمًا؟ | kari:ma: ‖ | kari:ma: α |
| الإِسلَام | ʔalʔisla:m | ʔalʔisla:m | **Harakat (ـَ ـُ ـِ)** | | |
| إسلَام | ʔisla:m | ʔisla:m | بَـابَ | ba:ba | ba:ba |
| كُؤُوس | kuʔu:s | kuʔu:s | بَرْدٍ | bardin | barΦdin μ |
| فُؤَاد | fuʔa:d | fuʔa:d | أبَ؛ | ʔab ‖ | ʔab • α |
| بُؤْبُؤْ | buʔbuʔ | buʔΦbuʔΦ | أبْ؛ | ʔab ‖ | ʔab • α |
| فِئَة | fiʔah | fiʔah | تَوثُ | tu:tu | tu:tu |
| كَـئِيب | kaʔi:b | kaʔi:b | كُلَّ | kul:i | kul:i μ |
| بريئَةٍ؛ | bari:ʔah ‖ | bri:ʔah α | أبْ؛ | ʔab ‖ | ʔab • α |
| **Lam (ل)** | | | مُدَرِّسًا | mudar:isan | mudar:isan μ |
| ألَـعَب | ʔalʕab | ʔalΦʕab | بِمَا | bima: | bim • a: |
| إلـتَمَس | ʔiltamas | ʔilΦtamas | حِينَ | hi:na | hi:na |
| لَـعَب | laʕab | laʕab | **Tanween (ـً ـٌ ـٍ)** | | |
| تَـل | tal | tal | بَابًا | ba:ban | μ ba:ban μ |
| مَال | ma:l | ma:l | بَابًا. | ba:ba: ‖ | ba:ba: α |
| وَالـوُد | walwud | walwud | بَابٌ | ba:bun | μ ba:bun μ |
| وَالـوُد | walwud | walwud | بَابٌ. | ba:b ‖ | ba:bΦ α |
| وَالـئِين | wat:i:n | wa • t:i:n | بَابٍ | ba:bin | μ ba:bin μ |
| الـئِينَ | ʔat:i:na | ʔat:i:na | بَأبٍ . | ba:b ‖ | ba:bΦ α |
| **Waw (و) and Ya (ي)** | | | أيٌّ | ʔaj:in | ʔaj:in |
| تُـوت | tu:t | tu:t | مِنَّى | minan | minan |
| مَـوز | mawz | mawz | مِنَّى؟ | mina: ‖ | mina: α |
| وَاحِد | wa:hid | wa:hid | **Ta' Marbutah (ة)** | | |
| تِـين | ti:n | ti:n | زُرْتُ المَدْرَسَـةَ وَفَرِحْتُ. | zurtu⌣lmadrasata wafariħt ‖ | zurΦtu⌣lmadΦrasata μ wafariħΦt • α |
| بَـيّـت | baj:at | baj:at | المَدْرَسَـةِ. | ʔalmadrasah ‖ | ʔalmadΦrasahΦ α |
| يَـد | jad | jad | زُرْتُ المَدْرَسَـةَ. | zurtul⌣madrasah ‖ | zurΦtu⌣lmadΦrasah • α |

TABLE XIII. EVALUATION OF FULLY DIACRITIZED TASHKEELA SENTENCES. IPA IS THE EXPECTED PHONETIC TRANSCRIPTION FROM A LANGUAGE SPECIALIST, OUT IS THE SYSTEM OUTPUT, AND DIFFER EXPLAINS THE VARIANCE BETWEEN IPA AND OUT. AS ILLUSTRATED IN THE EXAMPLES, IT CAN BE SEEN THAT THE SYSTEM PERFORMED WELL ON A LARGE VARIETY OF TEXTS. NOTE THAT WE REMOVED /•/ AND /Φ/ FOR READABILITY; THE DIFFERENCES ARE IN RED

| | |
|---|---|
| Φ: zero duration pause, μ: short duration pause, ω: medium duration pause, α: long duration pause, ~: continuation, •: not pronounced; In IPA \|means short stop, and \|\|means long stop | |
| Input | ويُعاني الوَطنُ العَربيُّ بِشدّةٍ مِن هذِه الظاهِرةِ بِسبَبِ وُقُوعِه ضِمنَ النِّطاقِ الصَّحراويِّ وَشِبه الصَّحراويِّ المُمتَدِّ مِن شَمالِ أفريقيا إلى آسيا. وَتُشَكِّلُ نِسبةُ المَساحاتِ المُتَصَحِّرةِ والأراضي القابِلةِ في المنطِقةِ حَوالي مِن إجمالي المَساحةِ الكُلِّيّةِ، أي حَوالي مِن إجمالي المَناطِقِ المُتَصَحِّرةِ عَلى مُستوى العالَم. |
| IPA | waʒuʕa:ni~lwatˤanu~lʕarabij:u biʃid:atin min haðihi~ðˤ:a:hirati bisababi wuqu:ʕihi dˤimna~n:itˤˤa:qi~sˤ:ahra:wij:i wafibhi~sˤ:ahra:wij:i~lmumtad:i min ʃamaːli ʔafriːqja: ʔila: ʔaːsja: α watuʃakːilu nisbatu~lmisa:ha:ti~lmutasˤahːirati walʔara:dˤi~lqaːbilati fiː~lmantˤiqati hawa:laʒ min ʔidʒma:lij:i~lmisa:hati~lkul:ij:ah \|ʔaʒ hawa:laʒ min ʔidʒma:lij:i~lmanatˤˤiqi~lmutasˤahːirati ʕala: mustawa~lʕa:lam \|\| |
| Out | μ waʒuʕa:ni~lwatˤanu~lʕarabij:u μ bิʃid:atin μ min μ haðihi~ðˤ:a:hirati μ bisababi μ wuqu:ʕihi μ dˤimna~n:itˤˤa:qi~sˤ:ahra:wij:i μ wafibhi~sˤ:ahra:wij:i~lmumtad:i μ min μ ʃamaːli μ ʔafriːqja: μ ʔila: μ ʔaːsja: α μ watuʃakːilu μ nisbatu~lmisa:ha:ti~lmutasˤahːirati μ walʔara:dˤi~lqaːbilati μ fiː~lmantˤiqati μ hawa:laʒ μ min μ ʔidʒma:lij:i~lmisa:hati~lkul:ij:ah μ ʔaʒ hawa:laʒ μ min μ ʔidʒma:lij:i~lmanatˤˤiqi~lmutasˤahːirati μ ʕala: μ mustawa~lʕa:lam α |
| Differ | None |
| Input | والطالِبُ نَباتاتٌ بَحريّةٌ بَسيطةُ التكوين، مُعظَمُها قادِرٌ على إجراءِ عَمليّةِ التَّمثيلِ الضَّوئيِّ، حَيثُ تَستطيعُ أن تُنتِجَ زَيتًا نَباتيًّا، تَتِمُّ مُعالَجتُهُ كيميائيًّا للحُصولِ على الدِّيزل الحَيويِّ، القادِرِ على تَشغيلِ كبيرٍ مِن المُحرِّكات. |
| IPA | watˤ:aha:libu naba:ta:tun bahrij:atun basiːtˤatu~t:akwiːn \|muʕðˤˤamuha: qa:dirun ʕala: ʔidʒra:ʔi ʕamalij:ati~t:amθiːli~dˤˤ:aw:ij: \|hajθu tastatˤiːʕu ʔan tuntidʒa zajtan naba:tij:a: \|tatim:u muʕaːladʒatuhu ki:mja:ʔij:an lilhusˤˤuːli ʕala~d:iːzal~lhajawij: \|ʔalqa:diri ʕala: taʃɣiːli kaθiːrin mina~lmuhar:ika:t \|\| |
| Out | watˤ:aha:libu μ naba:ta:tun μ bahrij:atun μ basiːtˤatu~t:akwiːn μ ω μ muʕðˤˤamuha: μ qa:dirun μ ʕala: μ ʔidʒra:ʔi μ ʕamalij:ati~t:amθiːli~dˤˤ:aw:ij: μ ω μ hajθu μ tastatˤiːʕu μ ʔan μ tuntidʒa μ zajtan μ naba:tij:a: μ ω μ tatim:u μ muʕaːladʒatuhu μ ki:mja:ʔij:an μ lilhusˤˤuːli μ ʕala~d:iːzal μ lhajawij: μ ω μ ʔalqa:diri μ ʕala: μ taʃɣiːli μ kaθiːrin μ mina~lmuhar:ika:t α |
| Differ | Due to the lack of a word-final diacritic in الدِّيزل, our system does not connect it to the next word even though it pronounces it correctly as seen. Please note that الدِّيزل is a loan word "the diesel" ʕala~d:iːzal μ lhajawij: ʕala~d:iːzal~lhajawij: |
| Input | يَذكُرُ أنّ هذِه القائمة تُسلِّط الضّوءَ كُلَّ عام على الأشخاص الّذين أسهَموا في مَجالات السِّياسة والرِّياضة والفنّ والأعمال وغَيرِها في جميع أنحاء العالم. |
| IPA | juðkaru ʔan:a ha:ðihi~lqa:ʔimata tusal:itˤu~dˤˤ:aw:ʔa kul:a ʕa:min ʕala~lʔaʃχa:sˤˤi~l:aði:na ʔashamu: fi: madʒa:la:ti~s:ija:sati war:ija:dˤˤati walfani: walʔaʕma:li wawaʒriha: fi: dʒami:ʕi ʔanha:ʔi~lʕa:lam \|\| |
| Out | juðkaru μ ʔan:a μ ha:ðihi~lqa:ʔimata μ tusal:itˤu~dˤˤ:aw:ʔa μ kul:a μ ʕa:min μ ʕala~lʔaʃχa:sˤˤi~l:aði:na μ ʔashamu: μ fi: μ madʒa:la:ti~s:ija:sati μ war:ija:dˤˤati μ walfani: μ walʔaʕma:li μ wawaʒriha: μ fi: μ dʒami:ʕi μ ʔanha:ʔi~lʕa:lam α |
| Differ | None |
| Input | ويُوجَدُ بِجامع القَزوِيِين بابًا، مِن أبرزِها بابُ الشُّمّاعين وَهُوَ البابُ الرَّئيسيُّ، وَبابُ الحُفاةِ، وَبابُ الوَرد. |
| IPA | waʒu:dʒadu bidʒa:miʕi~lqarawij:i:na ba:ba: \|min ʔabraziha: ba:bu~ʃ:am:a:ʕi:na wahuwa~lba:bu~r:a?i:sij: \|waba:bu~lhufa:h \|waba:bu~lward \|\| |
| Out | waʒu:dʒadu μ bidʒa:miʕi~lqarawij:i:na μ ba:ba: μ ω μ min μ ʔbraziha: μ ba:bu~ʃ:am:a:ʕi:na μ wahuwa~lba:bu μ r:a?i:sij: μ ω μ waba:bu~lhufa:h μ ω μ waba:bu~lward α |
| Differ | The reason behind the difference in أبرزِها pronunciation of the system and the expected pronunciation was the lack of a diacritic on the Alif ا thus making it an incomplete diacritization of the word, which was beyond our scope |
| Input | . الكَلبُ أكبَرُ مِن القِطّ |
| IPA | ʔalkalbu ʔakbaru mina~lqitˤˤ: |
| Out | ʔalkalbu μ ʔkbaru μ mina~lqitˤˤ: α |
| Differ | ʔakbaru vs ʔkbaru due to the lack of diacritic on ا |
| Input | طائرةٌ رائعةُ التَّصميم تَختَرِقُ سُرعَتُها حاجِزَ الصَّوتِ وَتَتَجاوَزُهُ للضّعف. اختِصارُها المُدّة الزَّمَنيّة المُستغرِقة في الطَّيران أدَى إلى النِّصف أدَى إلى إحداثِها ثَورةً في مَجال النَّقل الجَوّيِّ. وَلكِن، تَوَقَّف العَمَلُ بِها نِهائيًّا عام ، فَما هُوَ السَّبَبُ؟ |
| IPA | tˤa:ʔiratun ra:ʔiʕatu~t:asˤˤmiːmi taχtariqu surʕatuha: ha:dʒiza~sˤˤ:awti watatadʒa:wazuhu lidˤˤ:iʕf \|\|ʔiχtisˤˤa:ruha~lmud:ata~z:amanij:ata~lmustaɣriqata fiː~tˤˤ:ajara:ni ʔila: ʔaqal:i mina~n:isˤˤf ʔad:a: ʔila: ʔihda:θiha: θawratan fiː madʒa:li~n:aqli~ldʒaw:ij: \|\|walakin \|tawaqːafa~lʕamalu biha: niha:ʔij:an ʕaːma: fama: huwa~s:abab \|\| |
| Out | tˤa:ʔiratun μ ra:ʔiʕatu~t:asˤˤmiːmi μ taχtariqu μ surʕatuha: μ ha:dʒiza~sˤˤ:awti μ watatadʒa:wazuhu μ lidˤˤ:iʕf μ α χtisˤˤa:ruha~lmud:ata~z:amanij:ata~lmustaɣriqata μ fiː~tˤˤ:ajara:ni μ ʔila: μ ʔaqal:i μ mina~n:isˤˤf μ ʔad:a: μ ʔila: μ ʔihda:θiha: μ θawratan μ fiː μ madʒa:li~n:aqli~ldʒaw:ij: μ α μ walakin ω μ tawaqːafa~lʕamalu μ biha: μ niha:ʔij:an μ ʕaːma: μ fama: μ huwa~s:abab α |
| Differ | The lack of mad in the spelling of لكن is the reason our output did not pronounce the long vowel /a:/ in the word and instead pronounced it as the short vowel /a/ |
| Input | . الدّانِمارك رَفَضَت هذِه السّنة استِقبال لاجِئًا كانوا ضِمنَ حِصَّتها لِهذا العام |
| IPA | ʔad:a:nima:rku rafadˤat ha:ðihi~s:anata~stiqba:la la:dʒiʔan ka:nu: dˤˤimna hisˤˤatiha: liha:ða~lʕa:m \|\| |
| Out | ʔad:a:nima:rku μ rafadˤat μ haðihi~s:anata~stiqba:la μ μ la:dʒiʔan μ ka:nu: μ dˤˤimna μ hisˤˤatiha: μ lihaða~lʕa:m α |
| Differ | The same word هذا is misspelled twice and lacks the mad which gives the long vowel pronunciation ha:ðihi vs haðihi |
| Input | وأكّد الأكاديميِّ الفلسطينيِّ المُنشَقّ العامّ للمُؤتَمر يَحيى جَبر أنّه يأتي يَتنظيم مِن جامعة النَّجاح الوَطنيّة بنابُلْس وَدائرة شُؤون المُغتَربين بمُنظَّمة التّحرير الفلسطينيّة. |
| IPA | waʔakːada~lʔaka:di:mij:u~lfilastˤiːnij:u~lmunasˤˤaqu~lʕa:m:u lilmuʔtamari jahja: dʒabr ʔan:ahu jaʔti: bitandˤˤiːmin min dʒa:miʕati~n:adʒa:hi~lwatˤˤanij:ati bina:bulusa wada:ʔirati ʃuʔu:ni~lmuɣtaribi:na bimunaðˤˤ:amati~t:ahri:ri~lfilastˤiːnij:ah \|\| |
| Out | waʔakːada~lʔaka:di:mij:u~lfilastˤiːnij:u~lmunasˤˤaqu~lʕa:m:u μ lilmuʔtamari μ jahja: μ dʒabr μ ʔan:ahu μ jaʔti: μ bitandˤˤiːmin μ min μ dʒa:miʕati~n:adʒa:hi~lwatˤˤanij:ati μ bina:bulusa μ wada:ʔirati μ ʃuʔu:ni~lmuɣtaribi:na μ bimunaðˤˤ:amati~t:ahri:ri~lfilastˤiːnij:ah α |
| Differ | None |
| Input | تُدَرِّس شركةُ غوغل السَّمّاح بإنشاء حِساباتٍ على الإنترنت للأطفال تحت سِنّ عامًا، وَمَنح آبائهم القُدرةَ على التَّحكُّم في كيفيّةِ استِخدام هذِه الخِدمة. |
| IPA | tadrusu ʃarikatu ɰu:ɰil~s:ama:ha biʔinʃa:ʔi hisa:ba:tin ʕala~lʔintarnit lilʔatˤˤfa:li tahta sin:i ʕa:ma: \|wamanha ʔa:ba:ʔihima~lqudrata ʕala~t:ahakːumi fi: kajfij:ati~stiχda:mi ha:ðihi~lχidmah \|\| |
| Out | tadrusu μ ʃarikatu μ ɰu:ɰil μ s:ama:ha μ biʔinʃa:ʔi μ hisa:ba:tin μ ʕala~lʔintarnit μ lilʔatˤˤfa:li μ tahta μ sin:i μ ʕa:ma: μ ω μ wamanha μ ʔa:ba:ʔihim μ lqudrata μ ʕala~t:ahakːumi μ fi: μ kajfij:ati~stiχda:mi μ haðihi~lχidmah α |
| Differ | The main reason for the differences between expected and out in this example is a lack of diacritics, the existence of loan words (غوغل "google") and the lack of mad ( ٓ ) in هذه |

TABLE XIV. EVALUATION OF THE FULLY DIACRITIZED WIKIPEDIA SENTENCES. IPA IS THE EXPECTED PHONETIC TRANSCRIPTION FROM WIKIPEDIA, OUT IS THE SYSTEM OUTPUT, AND DIFFER EXPLAINS THE VARIANCE BETWEEN IPA AND OUT. AS ILLUSTRATED BELOW, THE SYSTEM ACHIEVED A PERFECT SCORE ON THE EXAMPLES. PLEASE NOTE WE REMOVED /Φ/ AND /•/ FROM THE OUTPUT TO IMPROVE READABILITY

| Φ: zero duration pause, μ: short duration pause, ω: medium duration pause, α: long duration pause, _: continuation, •: not pronounced; In IPA \|means short stop and \|\|means long stop |
|---|

| Input | كانَت رِيح الشَمال تَتَجادَل وَالشَمس في أيّ مِنهُما كانَت أقوَى مِن الأُخرَى، وَإِذ بِمُسافِر يَظلَع مُتَلَفِّعًا بِعَباءةٍ سَميكَة. فاتَّفَقتا عَلَى اعتِبار السابِق في إخبار المُسافِر عَلَى خَلع عَباءتِه الأقوَى. عَصَفت رِيح الشَمال بأقصَى ما استَطاعَت مِن قوَّة. وَلكِن كُلَّما ازدادَ العَصف ازدادَ المُسافِر تَدَثُّرًا بِعَباءتِه، إلَى أن أُسقِط في يَد الرِّيح فَتَخَلَّت عَن مُحاوَلَتِها. بَعدَئذٍ سَطَعَت الشَمس بِدِفئِها، فَما كان مِن المُسافِر إلَّا أن خَلَع عَباءتَهُ عَلَى التَوّ. وَهَكَذا اضطُرَّت رِيح الشَمال إلَى الاعتِراف بأن الشَمس كانَت هِي الأقوَى. |
|---|---|
| IPA | kaːnat riːħu ʃːamaːli tatadʒaːdalu waʃːamsa fiː ʔajːin minhumaː kaːnat ʔaqwaː minaː lʔuxraː \|wa ʔið bimusaːfirin jatˤluʕu mutalafːiʕan biʕabaːʔatin samiːkah \|\|fatːafaqataː ʕala ʕtibaːri sːaːbiqi fiː ʔidʒbaːri lmusaːfiri ʕala xalʕi ʕabaːʔatihi lʔaqwaː: \|\|ʕasˤʕafat riːħu ʃːamaːli biʔaqsˤaː ma statˤaːʕat min quwːah \|wa laːkin kulːamaː zdaːda lʕasˤfu zdaːda lmusaːfiru tadaθːuran biʕabaːʔatih \|ʔila ʔan ʔusqitˤa fiː jadi riːħi fataxalːat ʕan muħaːwalatiha \|\|baʕdaʔiðin satˤaʕati ʃːamsu bidifʔiha \|fa maː kaːna mina lmusaːfiri ʔilːaː ʔan xalaʕa ʕabaːʔatahu ʕala tːaw \|\|wa haːkaða dˤtˤurat riːħu ʃːamaːli ʔila lʔiʕtiraːfi biʔanːa ʃːamsa kaːnat hija lʔaqwaː: |
| Out | kaːnat μ riːħu ʃːamaːli μ tatadʒaːdalu μ waʃːamsa μ fiː μ ʔajːin μ minhumaː μ kaːnat μ ʔaqwaː μ minaː lʔuxraː ω μ waʔið μ bimusaːfirin μ jatˤluʕu μ mutalafːiʕan μ biʕabaːʔatin μ samiːkah α μ fatːafaqata μ ʕala ʕtibaːri sːaːbiqi μ fiː μ ʔidʒbaːri lmusaːfiri μ ʕala μ xalʕi μ ʕabaːʔatihi lʔaqwaː α μ ʕasˤʕafat μ riːħu ʃːamaːli μ biʔaqsˤaː μ ma statˤaːʕat μ min μ quwːah α μ walaːkin μ kulːamaː zdaːda lʕasˤfu zdaːda lmusaːfiru tadaθːuran μ biʕabaːʔatih ω μ ʔilaː μ ʔan μ ʔusqitˤa μ fiː μ jadi riːħi μ fataxalːat μ ʕan μ muħaːwalatiha α μ baʕdaʔiðin μ satˤaʕati ʃːamsu μ bidifʔiha ω μ famaː μ kaːna μ mina lmusaːfiri μ ʔilːaː μ ʔan μ xalaʕa μ ʕabaːʔatahu μ ʕala tːaw α μ wahaːkaða dˤtˤurːat μ riːħu ʃːamaːli μ ʔila lʔiʕtiraːfi μ biʔanːa ʃːamsa μ kaːnat μ hija lʔaqwaː α |
| Differ | None |

| Input | عِندَما ذَهَبت إلَى المَكتَبَة. |
|---|---|
| IPA | ʕindamaː ðahabtu ʔila lmaktabah \|\| |
| Out | ʕindamaː μ ðahabtu μ ʔila lmaktabah α |
| Differ | None |

| Input | عِندَما ذَهَبت إلَى المَكتَبَة. |
|---|---|
| IPA | ʕindamaː ðahabtu ʔila lmaktabah \|\| |
| Out | ʕindamaː μ ðahabtu μ ʔila lmaktabah α |
| Differ | None |

| Input | لَم أجِد سِوَى هَذا الكِتاب القَديم |
|---|---|
| IPA | lam ʔadʒid siwaː haːða lkitaːbi lqadiːm |
| Out | lam μ ʔadʒid siwaː μ haːða lkitaːbi lqadiːm |
| Differ | None |

| Input | كُنت أُريد أن أقرَأ كِتابًا عَن تاريخ المَرأة في فَرَنسا |
|---|---|
| IPA | kuntu ʔuriːdu ʔan ʔaqraʔa kitaːban ʕan taːriːχi lmarʔati fiː faransa: |
| Out | kuntu ʔuriːdu μ ʔan μ ʔaqraʔa μ kitaːban μ ʕan μ taːriːχi lmarʔati μ fiː μ faransa: |
| Differ | None |

| Input | أنا أحِبُّ القِراءةَ كَثيرًا |
|---|---|
| IPA | ʔana: ʔuħibːu lqira:ʔata kaθiːran |
| Out | ʔana: μ ʔuħibːu lqira:ʔata μ kaθiːran |
| Differ | None |

Supplement 1: Arabic Orthography, Phonology, and Morphology
Compendium

*Abstract*—Concise and specific information on modern standard Arabic (MSA), which can also be used as a standalone MSA reference, is given as a background to the main text and covers topics, such as textual marks and fermatas that significantly affect the phonetic transcription of text transformations that are not normally discussed in other texts in English. Minimal consonant pairs, geminates, and vowels to indicate phonemic contrasts are also given. To avoid confusion, the original Arabic symbols were retained rather than using Roman transliteration. Other than minimal pairs, the compendium was compiled from various Arabic references (7; 30).

## A   Orthography

Modern Standard Arabic (MSA) is written cursively from right to left, with the letter shapes changing according to the position. MSA has forty-six characters; twenty-eight alphabet letters, ten non-alphabet letters, and eight diacritics; and ligatures (لا,لأ,لأ,لإ), which are letter combinations used when writing but are not counted as characters because they are only graphical representations. Tables XV and XVI show the MSA script alphabet and non-alphabet letters and the diacritics. Table XVI presents the alphabet letter shapes based on their position in a word, an example word containing the alphabet letter, its IPA transcription using segmental phonology, and the word meaning.

Table XVI introduces the ten non-alphabet letters, four (أ, إ, ئ, ؤ) of which are part of the five-member "Hamza sisters," and the fifth being the alphabet letter (ء). Five of the non-alphabet letters (ا, ى, ة, آ, ٱ) produce complexities as they map to one or more sounds based on their position in the word and the surrounding words; this is discussed in more detail in later sections. Kasheeda (ـ) is used for graphical justification and elongation and has no underlying pronunciation. The letter mad (٘) is part of MSA but is non-existent on computer keyboards and, therefore, is missing in modern texts and needs to be added to the thirteen words that contain it before any processing.

Table XVII lists the diacritics, which may not be at the start of a word, and divides the diacritics into three categories: Harakah (◌َ, ◌ِ, ◌ُ), Tanween (◌ً, ◌ٍ, ◌ٌ), and other (Shaddah ◌ّ; Sukoon ◌ْ). A Harakah character is pronounced as a short vowel, a Tanween character is pronounced as a combination of a short vowel and /n/ and can only occur at the end of a word, Sukoon (◌ْ) is a zero-length pause, and as Shaddah (◌ّ) indicates the gemination of the sound it follows, it cannot be preceded by a diacritic.

Diacritics cannot be consecutive, except for Shaddah (◌ّ), which is generally followed by Harakah and sometimes by Tanween or Sukoon. Other rules restrict a sequence of characters; for example, إ can only be followed by a kasra, أ is only followed by Sukoon, dhamma, or fatha, ؤ may not be followed by kasra, shaddah, and ya' and can only be preceded by dhama, ئ cannot be followed by a shaddah and is only preceded by kasra, and ء cannot start a word.

Five MSA letter groupings are related to pronunciation: Hamza, Wasl, Solar, and Lunar. The Hamza set {ئ ؤ ء إ أ} are pronounced as glottal stops, and the Wasl symbols {ك ل ت ب و} are characters that affect the pronunciation of ا; for example, if

any of the Wasl symbols precede ا when ا is at the start of the word, then ا is not pronounced.

The Solar set {ت ث د ذ ر ز س ش ص ض ط ظ ن ل} and the Lunar set {ب ج ح خ ع غ ف ق ك م ه و ي ء إ أ} are grouped because the Solar and Lunar letters affect the pronunciation of ل in a very specific character environment (when it is part of the definite article in Arabic: ال); for example, when a Solar letter follows ل, then ل is not pronounced, but when a Lunar letter follows ل, it is pronounced.

It is also important to describe the text markings as they not only correspond to "sounds" but also regulate the contextual pronunciation of the consonants as detailed in the rules presented in the main manuscript. Table XV details the marks and their corresponding fermatas.

TABLE XV. Marks and their Corresponding Pauses and Continuations

| Description | Mark | Mark symbol | Fermata | IPA symbol | System symbol |
|---|---|---|---|---|---|
| | | End of File, eof, | | | |
| Between paragraphs, sentences | Start of File tab, new line | sof \t, \n | Long duration pause | ‖ or (…) | α |
| Between phrases | . ! ; | !;.? | Medium duration pause | | or (.) | ω |
| Between words | space | \s | Short duration pause | (.) | μ |
| Within word | Not applicable | Not applicable | Zero duration pause | | • |
| Connected words | space | \s | Continuation | ‿ | ‿ |

TABLE XVI. Alphabetic Letters and Their Shapes in Different Word Positions. I: Isolated, B: Beginning, M: Middle, and E: End. Example Words and Meanings (gloss) are given in IPA with their Broad Segmental Pronunciation Transcriptions

| Alphabet Letters | | | | | | | Alphabet Letters | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| I | B | M | E | Word | IPA | Gloss | I | B | M | E | Word | IPA | Gloss |
| ء | ء | ء | ء | شعراء | /ʃuʕaraːʔ/ | poets | ض | ض | ضـ | ـض | ضفدع | /dˤufdaʕ/ | frog |
| ب | بـ | ـبـ | ـب | بيْت | /bajt/ | house | ط | ط | طـ | ـط | طائرة | /tˤaːʔirah/ | plane |
| ت | تـ | ـتـ | ـت | تل | /tal/ | hill | ظ | ظ | ظـ | ـظ | ظالم | /ðˤaːlim/ | who wrongs |
| ث | ثـ | ـثـ | ـث | ثاني | /θaːniː/ | second | ع | عـ | ـعـ | ـع | عين | /ʕajn/ | eye |
| ج | جـ | ـجـ | ـج | جلد | /dʒild/ | leather | غ | غـ | ـغـ | ـغ | غدّة | /ʁudːah/ | gland |
| ح | حـ | ـحـ | ـح | حليب | /haliːb/ | milk | ف | فـ | ـفـ | ـف | فيل | /fiːl/ | elephant |
| خ | خـ | ـخـ | ـخ | خل | /χal/ | vinegar | ق | قـ | ـقـ | ـق | قلم | /qalam/ | pen |
| د | د | ـد | ـد | دب | /dub/ | bear | ك | كـ | ـكـ | ـك | كتاب | /kitaːb/ | book |
| ذ | ذ | ـذ | ـذ | ذرة | /ðurah/ | corn | ل | لـ | ـلـ | ـل | لون | /lawn/ | color |
| ر | ر | ـر | ـر | رز | /ruz/ | rice | م | مـ | ـمـ | ـم | موز | /mawz/ | banana |
| ز | ز | ـز | ـز | زعتر | /zaʕtar/ | thyme | ن | نـ | ـنـ | ـن | نمر | /nimr/ | tiger |
| س | سـ | ـسـ | ـس | سلّم | /sulːam/ | ladder | ه | هـ | ـهـ | ـه | هلال | /hilaːl/ | crescent |
| ش | شـ | ـشـ | ـش | شلال | /ʃalːal/ | water fall | و | و | ـو | ـو | ولد | /walad/ | boy |
| ص | صـ | ـصـ | ـص | صبْر | /sˤabr/ | patience | ي | يـ | ـيـ | ـي | يوم | /jawm/ | day |

| Non-alphabet Letters | | | | | | | Non-alphabet Letters | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| I | B | M | E | Word | IPA | Gloss | I | B | M | E | Word | IPA | Gloss |
| ا | ا | ـا, ا | ـا | آسيا | /ʔaːsjaː/ | Asia | ا | ا | ـا, ا | ـا | اختبار | /ʔiχtibaːr/ | exam |
| ؤ | | ؤ, ـؤ | ؤ, ـؤ | مؤمن | /muʔmin/ | faithful | ى | | ـى, ى | ى | أنثى | /ʔunθaː/ | female |
| | | ـئـ, ئ | ئ, ـئ | طائرة | /tˤaːʔirah/ | plane | ة | | ـة, ة | ة | أنثى | /tˤaːʔirah/ | plane |
| أ | أ | ـأ, أ | أ, ـأ | أكتب | /ʔaktub/ | I write | آ | آ | ـآ, آ | ـآ | هذا | /haːðaː/ | this 'male' |
| إ | إ | إ, ـإ | إ, ـإ | إحسان | /ʔiħsaːn/ | goodness | ٱ | | | ـٱ | بسْم | /bism/ | in the name of |

TABLE XVII. Diacritics with Example usage, their Broad Segmental Pronunciation Transcriptions in IPA, and Meanings

| Diacritics | | Usage | IPA | Gloss | Diacritics | | Usage | IPA | Gloss |
|---|---|---|---|---|---|---|---|---|---|
| Fatha | ◌َ | وَلَد | /walad/ | a boy | Kasra | ◌ِ | فعِل | /fiʕil/ | a verb |
| Tanween Fath | ◌ً | إسْماً | /ʔisman/ | a name | Tanween Kasr | ◌ٍ | فعٍل | /fiʕlin/ | a verb |
| Dhamma | ◌ُ | دُبّ | /dub/ | a bear | Shaddah | ◌ّ | غدّة | /ʁudːah/ | a gland |
| Tanween Dham | ◌ٌ | رُزٌ | /ruzun/ | rice | Sukoon | ◌ْ | فعْل | /fiʕil/ | a verb |

## B   Segmental Phonology

MSA is a Semitic language with 55 consonants and six vowels. In addition to labio-dental and velar sounds, MSA is rich in glottal, uvular, and pharyngeal sounds such as /ʕ/, and has regular and velarized or pharyngealized pairs, such as /d/

and /dˤ/. The geminated counterparts of the phonemes are also MSA phonemes.

MSA has eight plosives; one bilabial /b/, four alveolars /t/, /d/, /tˤ/, /dˤ/, one velar /k/, one uvular /q/, and one glottal /ʔ/); two nasals; bilabial /m/ and alveolar /n/; one alveolar trill; /r/; thirteen fricatives; one labiodental /f/, three dental /θ/, /ð/, /ðˤ/, three alveolars /s/, /z/, /sˤ/, one postalveolar /ʃ/, two uvular /χ/, /ʁ/, two pharyngeal /ħ/, /ʕ/, and one glottal /h/; two approximants; one bilabial /w/ and one palatal /j/; one postalveolar affricate; /d͡ʒ/; and an alveolar lateral approximant; /l/. MSA has only six long and short vowels: /aː/, /iː/, /uː/, /a/, /i/, /u/. Table XIX shows the consonant chart, with the consonants based on voicing, pharyngealization, place of articulation, and manner of articulation. Table XX enumerates the geminated consonantal phonemes with examples. Table XVIII presents the vowel chart. Minimal pairs that validate the phonemes are in Appendix A.

Phonemes are also grouped based on the pronunciation of their related character: coronals; dental, alveolar, and postalveolar, with /θ/, /ð/, /ðˤ/, /r/, /n/, /t/, /d/, /tˤ/, /dˤ/, /s/, /z/, /sˤ/, /l/, /ʃ/, /d͡ʒ/ being the phonemes the Solar letters map to; and non-coronals; bilabial, labiodental, palatal, velar, uvular, pharyngeal, and glottal, with /b/, /m/, /w/, /f/, /j/, /k/, /q/, /χ/, /ʁ/, /ħ/, /ʕ/, /ʔ/, /h/ being the phonemes Lunar letters map to. Hamzah sisters map to the glottal stop, Harakah map to short vowels, Tanween maps to a short vowel followed by /n/ depending on the context, and Shaddah causes gemination.

TABLE XVIII. VOWEL CHART: UPPER LEFT IS NORMAL UNROUNDED, UPPER RIGHT IS NORMAL ROUNDED, LOWER LEFT IS LENGTHENED AND UNROUNDED, AND THE LOWER RIGHT IS LENGTHENED AND ROUNDED

|  | Front | Central | Back |
|---|---|---|---|
| Close (high) | i<br>iː |  | u<br>uː |
| Mid |  |  |  |
| Open (low) | a<br>aː |  |  |

TABLE XIX. CONSONANT CHART : THE SYMBOL ON THE TOP RIGHT IS NORMAL VOICED, THE SYMBOL ON THE TOP LEFT IS NORMAL UNVOICED, THE SYMBOL ON THE BOTTOM RIGHT IS PHARYNGEALIZED VOICED, AND THE SYMBOL ON THE BOTTOM LEFT IS PHARYNGEALIZED UNVOICED

|  | Bilabial | Labio-dental | Dental | Alveolar | Post-alveolar | Palatal | Velar | Uvular | Pharyngeal | Glottal |
|---|---|---|---|---|---|---|---|---|---|---|
| Plosive | b |  |  | t    d<br>tˤ   dˤ |  |  | k | q |  | ʔ |
| Nasal | m |  |  | n |  |  |  |  |  |  |
| Trill |  |  |  | r |  |  |  |  |  |  |
| Fricative |  | f | θ   ð<br>ðˤ | s   z<br>sˤ | ʃ |  |  | χ   ʁ | ħ   ʕ | h |
| Affricate |  |  |  |  | d͡ |  |  |  |  |  |
| Approximant | w |  |  |  |  | j |  |  |  |  |
| Lateral Approximant |  |  |  | l |  |  |  |  |  |  |

## C   MORPHOLOGY

Morphology deals with the internal structure of words. More specifically, it dictates the composition of a word from smaller meaningful units called morphemes. There are two approaches to morphology; form-based and functional. Form-based morphology considers the form of the units making up a word, their interactions, and how they relate to the word's overall form. Functional morphology is about the function of the units inside

TABLE XX. MSA GEMINATED PHONEMES. ALL CONSONANTS EXCEPT FOR THE GLOTTAL STOP. THE EXAMPLES BELOW SHOW WORDS WITH GEMINATED CONSONANTS

| Phone | Word | IPA | Gloss | Phone | Word | IPA | Gloss |
|---|---|---|---|---|---|---|---|
| [bː] | تبًا | /tabːan/ | perish! | [tˤː] | الطبيب | /ʔtˤːabiːb/ | the doctor |
| [tː] | التل | /ʔtːal/ | the hill | [ðˤː] | الظل | /ʔðˤːil/ | the shadow |
| [θː] | الثلاثاء | /ʔθːulaːθaːʔ/ | Tuesday | [ʕː] | لعّب | /laʕːaba/ | he played with |
| [d͡ʒː] | أجّل | /ʔd͡ʒːala/ | delayed | [ʁː] | صغر | /sauʁːara/ | he made smaller |
| [hː] | وحّد | /wahːda/ | united | [fː] | أفّ | /ʔufːin/ | expressing impatience/contempt |
| [χː] | أخّر | /ʔaχːara/ | delayed | [qː] | وقّت | /waqːata/ | he timed |
| [dː] | الدّمار | /ʔdːamaːr/ | the destruction | [kː] | أكّل | /ʔkːala/ | he fed |
| [ðː] | الذّنب | /ʔðːanb/ | the sin | [lː] | اللمس | /ʔlːams/ | the touch |
| [rː] | الرّز | /ʔrːuz/ | the rice | [mː] | نمّام | /namːam/ | he who spreads scandals |
| [zː] | الزّوج | /ʔzːawd͡ʒ/ | the husband | [nː] | النّمر | /ʔnːimr/ | the tiger |
| [sː] | السّماء | /ʔsːamaːʔ/ | the sky | [hː] | وهّم | /wahːam/ | puzzled somebody |
| [ʃː] | الشّمس | /ʔʃːams/ | the sun | [wː] | توّاب | /tawːab/ | repentant |
| [sˤː] | الصّباح | /ʔsˤːabaːh/ | the morning | [jː] | جيّد | /d͡ʒajːit/ | good |
| [dˤː] | الضّفدع | /ʔdˤːufdaʕ/ | the frog |  |  |  |  |



Fig. 5. Arabic word morpheme breakdown. A word is a concatenation of a prefix, stem, and suffix (concatenative). A stem is a meaning-bearing unit that can be further decomposed into its root and pattern (templatic). The root gives the core meaning and the pattern provides the part of speech (POS, category) and other linguistic properties, such as number, tense, and gender. This image uses the Buckwalter transliteration scheme (www.qamus.org/transliteration.htm).

a word and how they affect its overall syntactic and semantic behavior.

Fig. 5 illustrates the structure of Arabic words. Arabic utilizes form-based morphology and has concatenative and templatic morphemes (smallest units in a word). Concatenative morphology is centered on stems and affixes (prefixes, suffixed, circumfixes), and the morphemes are generally concatenated in a sequence to produce a surface form (word). Morphological grammar that constructs stems from the interdigitation (interleaving) of the root and pattern is called templative morphology. In Arabic, morphological form and function are independent although most templatic processes are derivational and most concatenative processes are inflectional. Derivational functional morphology is concerned with creating new words from other words, and in inflectional morphology, the meaning and part of speech remain the same (31).

The two broad morpheme classes in concatenative morphology are stems and affixes. Stems are the core meaning-bearing units, and affixes are added before and after stems to alter the meaning and function. An affix may be a prefix (concatenated before the stem), a suffix (concatenated after the stem), or a circumfix, with parts added before and after a stem. The stem can be templatic (derived) or non-templatic (fixed). Templatic stems are stems that can be formed using templatic morphemes, whereas non-templatic word stems are not derivable from templatic morphemes and tend to be of foreign origin or names.

REFERENCES

[1] D. Jurafsky and J. H. Martin, Eds., *Speech and Language Processing: An Introduction to Natural Language Processing, Computational Linguistics, and Speech Recognition*, 2020.

[2] F. Seifart, ``Orthography development,'' *Essentials of language documentation*, pp. 275--299, 2006.

[3] R. Hetzron, Ed., *The Semitic Languages*. Routledge, 1997.

[4] M. Hulden, ``Foma: a finite-state compiler and library,'' in *Proceedings of the Demonstrations Session at EACL 2009*, 2009, pp. 29--32.

[5] N. Halabi, ``Modern standard arabic phonetics for speech synthesis,'' Ph.D. dissertation, University of Southampton, 2016.

[6] T. Zerrouki and A. Balla, ``Tashkeela: Novel corpus of arabic vocalized texts, data for auto-diacritization systems,'' *Data in Brief*, vol. 11, pp. 147 -- 151, 2017.

[7] A. Dahdah and G. M. Abdulmassih, *A dictionary of Arabic grammar in charts and tables*. Librairie du Liban, 1981.

[8] M. b. A. B. Al-Razi, ``Mukhtar al-sihah,'' *Beirut: Dar al-Namudzajiyah*, 1999.

[9] A. El-Dahdah, E. Matar, and G. M. Abdul-Massih, ``majam qawaaid al-arabiiat al-aalamiiat (a dictionary of universal arabic grammar)/معجم قواعد العربية العالمية,'' 1990.

[10] A. Pasha, M. Al-Badrashiny, M. T. Diab, A. El Kholy, R. Eskander, N. Habash, M. Pooleery, O. Rambow, and R. Roth, ``Madamira: A fast, comprehensive tool for morphological analysis and disambiguation of arabic.'' in *Lrec*, vol. 14, no. 2014, 2014, pp. 1094--1101.

[11] K. R. Beesley, ``Finite-state morphological analysis and generation of arabic at xerox research: Status and plans in 2001,'' in *ACL Workshop on Arabic Language Processing: Status and Perspective*, vol. 1. Citeseer, 2001, pp. 1--8.

[12] N. Y. Habash and O. C. Rambow, ``Magead: A morphological analyzer and generator for the arabic dialects,'' 2006.

[13] K. Darwish, M. Diab, and N. Habash, ``Proceedings of the acl workshop on computational approaches to semitic languages,'' in *Proceedings of the ACL Workshop on Computational Approaches to Semitic Languages*, 2005.

[14] M. Attia, P. Pecina, A. Toral, L. Tounsi, and J. van Genabith, ``An open-source finite state morphological transducer for modern standard arabic,'' in *Proceedings of the 9th International Workshop on Finite State Methods and Natural Language Processing*, 2011, pp. 125--133.

[15] K. Darwish, ``Building a shallow arabic morphological analyser in one day,'' in *Proceedings of the ACL-02 workshop on Computational approaches to semitic languages*, 2002.

[16] T. Buckwalter, ``Buckwalter arabic morphological analyzer version 1.0,'' *Linguistic Data Consortium, University of Pennsylvania*, 2002.

[17] D. Graff, M. Maamouri, B. Bouziri, S. Krouna, S. Kulick, and T. Buckwalter, ``Standard arabic morphological analyzer (sama),'' *Linguistic Data Consortium LDC2009E73*, 2010.

[18] O. Smrz, ``Elixirfm--implementation of functional arabic morphology,'' in *Proceedings of the 2007 workshop on computational approaches to Semitic languages: common issues and resources*, 2007, pp. 1--8.

[19] R. Roth, O. Rambow, N. Y. Habash, M. Diab, and C. Rudin, ``Arabic morphological tagging, diacritization, and lemmatization using lexeme models and feature ranking,'' 2008.

[20] E. L. Antworth, ``Pc-kimmo: a two-level processor for morphological analysis,'' *Summer Institute of Linguistics*, 1990.

[21] L. Karttunen, *Finite-state lexicon compiler*. Xerox Corporation, Palo Alto Research Center, 1993.

[22] G. Kiraz, ``Multi-tape two-level morphology: a case study in semitic non-linear morphology,'' *arXiv preprint cmp-lg/9407023*, 1994.

[23] M. Mohri, F. Pereira, and M. Riley, ``Weighted finite-state transducers in speech recognition,'' *Computer Speech Language*, vol. 16, no. 1, pp. 69--88, 2002. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0885230801901846

[24] M. T. Diab, ``Second generation amira tools for arabic processing : Fast and robust tokenization , pos tagging , and base phrase chunking,'' 2009.

[25] A. A. Al-Nassir, ``Sibawayh the phonologist: A critical study of the phonetic and phonological theory of sibawayh as presented in his treatise? al kitab?'' Ph.D. dissertation, University of York, 1985.

[26] Y. A. El-Imam, ``Phonetization of arabic: rules and algorithms,'' *Computer Speech & Language*, vol. 18, no. 4, pp. 339--373, 2004.

[27] F. Biadsy, N. Habash, and J. Hirschberg, ``Improving the arabic pronunciation dictionary for phone and word recognition with linguistically-based pronunciation rules,'' in *Proceedings of human language technologies: The 2009 annual conference of the North American chapter of the association for computational linguistics*, 2009, pp. 397--405.

[28] A. Ramsay, I. Alsharhan, and H. Ahmed, ``Generation of a phonetic transcription for modern standard arabic: A knowledge-based model,'' *Computer Speech & Language*, vol. 28, no. 4, pp. 959--978, 2014.

[29] M. Maamouri, A. Bies, T. Buckwalter, and W. Mekki, ``The penn arabic treebank: Building a large-scale annotated arabic corpus,'' in *NEMLAR conference on Arabic language resources and tools*, vol. 27. Cairo, 2004, pp. 466--467.

[30] J. Åkesson, ``Arabic morphology and phonology: Based on the marāḥ al-arwāḥ by aḥmad b.ʿaī b. mas ʿūd,'' in *Arabic Morphology and Phonology*. Brill, 2017.

[31] A. A. S. Farghaly, ``Arabic computational linguistics,'' *(No Title)*, 2010.

[32] M. Sipser, *Introduction to the Theory of Computation*. Cengage Learning, 2012.

[33] R. M. Kaplan and M. Kay, ``Regular models of phonological rule systems,'' *Computational linguistics*, vol. 20, no. 3, pp. 331--378, 1994.

[34] K. Koskenniemi, ``Two-level morphology,'' Ph.D. dissertation, Ph. D. thesis, University of Helsinki, 1983.

[35] L. Karttunen *et al.*, ``Kimmo: a general morphological processor,'' in *Texas Linguistic Forum*, vol. 22. Texas, USA, 1983, pp. 163--186.

[36] J. Bear, ``A morphological recognizer with syntactic and phonological rules,'' in *COLING*, vol. 86, no. 10.3115, 1986, pp. 991 365--991 445.

[37] ------, ``Morphology with two-level rules and negative rule

features," in *Coling Budapest 1988 Volume 1: International Conference on Computational Linguistics*, 1988.

[38] A. W. Black, G. Ritchie, S. Pulman, and G. Russell, ``Formalisms for morphographemic description," in *Third Conference of the European Chapter of the Association for Computational Linguistics*, 1987.

[39] K. Beesley, T. Buckwalter, and S. Newton, ``Two-level finite-state analysis of arabic morphology," in *Proceedings of the Seminar on Bilingual Computing in Arabic and English*, 1989, pp. 6--7.

[40] H. Trost, ``The application of two-level morphology to non-concatenative german morphology," 1990.

[41] G. D. Ritchie, *Computational morphology: practical mechanisms for the English lexicon*. MIT press, 1992.

[42] E. L. Antworth, ``Morphological parsing with a unification-based word grammar," in *Proceedings of the North Texas Natural Language Processing Workshop*. Citeseer, 1994, pp. 24--32.

[43] H. Ruessink, *Two-level formalisms*. Katholieke Universiteit, 1989.

[44] D. Carter, ``Rapid development of morphological descriptions for full language processing systems," *arXiv preprint cmp-lg/9502006*, 1995.

[45] E. Grimley-Evans, G. A. Kiraz, and S. G. Pulman, ``Compiling a partition-based two-level formalism," *arXiv preprint cmp-lg/9605001*, 1996.

[46] S. Bird, E. Klein, and E. Loper, *Natural language processing with Python: analyzing text with the natural language toolkit*. " O'Reilly Media, Inc.", 2009.

[47] C. D. Johnson, *Formal aspects of phonological description*. Walter de Gruyter GmbH & Co KG, 2019, vol. 3.

[48] K. R. Beesley and L. Karttunen, ``Finite-state morphology: Xerox tools and techniques," *CSLI, Stanford*, pp. 359--375, 2003.

[49] S. Bird and T. M. Ellison, ``One-level phonology: Autosegmental representations and rules as finite automata," *Computational Linguistics*, vol. 20, no. 1, pp. 55--90, 1994.

[50] K. R. Beesley and L. Karttunen, ``Finite-state nonconcatenative morphotactics," *arXiv preprint cs/0006044*, 2000.

[51] J. J. McCarthy, ``A prosodic theory of nonconcatenative morphology," *Linguistic inquiry*, vol. 12, no. 3, pp. 373--418, 1981.

[52] M. Kay, ``Nonconcatenative finite-state morphology," in *Third Conference of the European Chapter of the Association for Computational Linguistics*, 1987.

[53] J. A. Goldsmith, *Autosegmental and metrical phonology*. Basil Blackwell Cambridge, 1990, vol. 1.

[54] J. McCarthy and A. Prince, ``Prosodic morphology and templatic morphology," in *Perspectives on Arabic linguistics II: papers from the second annual symposium on Arabic linguistics*. John Benjamins Pub. Co. Amsterdam, 1990, pp. 1--54.

[55] J. J. McCarthy and A. Prince, ``Generalized alignment," in *Yearbook of morphology 1993*. Springer, 1993, pp.

79--153.

[56] L. Kataja and K. Koskenniemi, ``Finite-state description of semitic morphology: A case study of ancient accadian," in *Coling Budapest 1988 Volume 1: International Conference on Computational Linguistics*, 1988.

[57] K. Beesley, ``Finite-state description of arabic morphology," in *Proceedings of the Second Cambridge Conference: Bilingual Computing in Arabic and English*, 1990, pp. 5--7.

[58] K. R. Beesley, ``Computer analysis of arabic morphology: A two-level approach with detours," in *Perspectives on Arabic Linguistics III: Papers from the Third Annual Symposium on Arabic Linguistics*. John Benjamin's Publishing Company Amsterdam, 1991, pp. 155--172.

[59] ------, ``Arabic finite-state morphological analysis and generation," in *COLING 1996 Volume 1: The 16th International Conference on Computational Linguistics*, 1996.

[60] R. W. Sproat, *Morphology and computation*. MIT press, 1992.

[61] S. G. Pulman and M. R. Hepple, ``A feature-based formalism for two-level phonology: a description and implementation," *Computer Speech & Language*, vol. 7, no. 4, pp. 333--358, 1993.

[62] A. Narayanan and L. Hashem, ``On abstract finite-state morphology," in *Conference of the European Chapter of the Association for Computational Linguistics*, 1993.

[63] K. R. Beesley, ``Arabic morphology using only finite-state operations," in *SEMITIC@COLING*, 1998.

[64] G. A. Kiraz, ``Multitiered nonlinear morphology using multitape finite automata: a case study on syriac and arabic," *Computational Linguistics*, vol. 26, pp. 77--105, 2000.

[65] A. Kornai, ``Formal phonology," 2018.

[66] B. Wiebe, ``Modelling autosegmental phonology with multi-tape finite state transducers," 1992.

### Appendix A
#### A. Minimal Pairs/near-minimal Pairs (Evidence for the MSA Phonemic Inventory)

The sounds of Modern Standard Arabic (MSA) could be classified as phonemes or allophones. In order to differentiate between phonemes and allophones, a list of minimal or near-minimal pairs have been found for all the phonemes in MSA. Two things to note include: (1) The diacritics convey the vowel sounds, which is why the correct diacritics are important to correctly phonetically transcribe orthography. (2) There are MSA characters that convey the vowel sounds.

Table XXI lists the minimal / near minimal pairs for non-geminated consonants. Table XXII lists the minimal / near minimal pairs for geminated consonants that are compared to the non-geminated version of the consonant. Table XXIII list the minimal / near minimal pairs for the short and long vowels, and Table XXIV conveys that the long and short vowels are contrastive.

TABLE XXI. Minimal Consonant Pairs

| Contrastive Phones | | Shared Property | Minimal Pair / Near-Minimal Pair | | |
|---|---|---|---|---|---|
| Phone 1 | Phone 2 | | Word | IPA | Gloss |
| /t/ | /d/ | alveolar stops | دُب | [dub] | bear |
| | | | تُب | [tub] | repent |
| /s/ | /sˤ/ | voiceless alveolar fricatives | سُورَة | [surah] | chapter of the Qur'an |
| | | | صُورَة | [sˤurah] | picture |
| /l/ | /r/ | liquids | لَان | [la:n] | relent, soften |
| | | | رَان | [ra:n] | seize; overcome; prevail |
| /ʕ/ | /ħ/ | pharyngeal fricatives | غُلِب | [ʕulːib] | was boxed |
| | | | حُلِب | [ħulːib] | was milked |
| /q/ | /k/ | unvoiced plosives | قَلْب | [qalb] | heart |
| | | | كَلْب | [kalb] | dog |
| /m/ | /n/ | voiced nasals | مَال | [mala] | swayed |
| | | | نَال | [nala] | gained |
| /ʃ/ | /d͡ʒ/ | postalveolar | أشمل | [ʔaʃmal] | more general |
| | | | أجمل | [ʔad͡ʒmal] | more beautiful |
| /ð/ | /ðˤ/ | voiced dental fricatives | ذَلك | [ðalik] | that 'male' |
| | | | ظَالِم | [ðˤalim] | unjust/ oppressive |
| /z/ | /s/ | alveolar fricatives | زَاهِر | [za:hir] | blooming |
| | | | سَاهِر | [sa:hir] | up late into the night |
| /q/ | /χ/ | voiceless uvular fricatives | قَدَم | [qadam] | leg |
| | | | خَدَم | [χadam] | servants |
| /ʃ/ | /f/ | voiceless fricatives | شَعَل | [ʃaqala] | lit |
| | | | فَعَل | [faqala] | 'he' did |
| /ʁ/ | /ʕ/ | voiced fricatives | غالي | [ʁa:liː] | expensive |
| | | | عالي | [ʕa:liː] | high |
| /b/ | /m/ | voiced bilabials | بَال | [ba:la] | urinated |
| | | | مَال | [ma:la] | tilted |
| /ʔ/ | /h/ | unvoiced glottals | مُؤْمِن | [muʔmin] | faithful |
| | | | مَهْمِل | [muhmil] | careless |
| /θ/ | /ð/ | dental fricatives | ثَمَر | [θamar] | fruit |
| | | | ذَهَب | [ðahab] | gold |
| /j/ | /w/ | voiced approximants | بَيْت | [bajt] | house |
| | | | مَوْت | [mawt] | death |
| /t/ | /tˤ/ | voiceless alveolar plosives | تَبِيت | [tabiːt] | she sleeps over |
| | | | طَبِيب | [tˤabiːb] | doctor |
| /d/ | /dˤ/ | voiced alveolar plosives | دَمَار | [dama:r] | destruction |
| | | | ضَمِير | [dˤamiːr] | conscience |

TABLE XXII. Geminated Characters are Language Phonemes and Contrast the Nongeminated Phonemes

| Phoneme | Word (geminated) | IPA | Gloss | Word (un-geminated) | IPA | Gloss |
|---|---|---|---|---|---|---|
| b | حبّ | /habːa/ | had loved | حب | /hab/ | a seed |
| t | التلّ | /ʔatːal/ | the hill | تل | /tal/ | hill |
| θ | الثّلاثاء | /aθːulaːθaːʔ/ | Tuesday | تمر | /θamar/ | fruit |
| d͡ʒ | أجّل | /ʔadʒːala/ | delayed | أجل | /ʔadʒal/ | time |
| h | وحّد | /wahːda/ | had united | وحد | /wahada/ | united |
| χ | أخّر | /ʔaχːara/ | delayed | آخر | /ʔaχar/ | other |
| d | الدّمار | /ʔadːamaːr/ | the distruction | دمار | /damaːr/ | distruction |
| ð | الذّنب | /ʔaðːanb/ | the sin | ذنب | /ðanb/ | sin |
| r | الرّز | /ʔarːuz/ | the rice | رز | /ruz/ | rice |
| z | الزّوج | /ʔzːawdʒ/ | the husband | زوج | /zawdʒ/ | husband |
| s | السّماء | /ʔasːamaːʔ/ | the sky | سماء | /samaːʔ/ | sky |
| ʃ | الشّمس | /ʔaʃːams/ | the sun | شمس | /ʃams/ | sun |
| sˤ | الضّباح | /ʔasˤːabah/ | the morning | صباح | /sˤabaːh/ | morning |
| dˤ | الضّفدع | /ʔadˤːufdaʕ/ | the frog | ضفدع | /dˤufdaʕ/ | frog |
| tˤ | الطّبيب | /ʔatˤːabiːb/ | the doctor | طبيب | /tˤabiːb/ | doctor |
| ðˤ | الظّل | /ʔaðˤːil/ | the shadow | ظل | /ðˤil/ | shadow |
| ʕ | لعّب | /laʕːaba/ | played with | لعب | /laʕab/ | played |
| ʁ | صغّر | /saʁːara/ | made smaller | صغر | /saʁar/ | became smaller |
| f | أفّ | /ʔufːin/ | expressing impatience or contempt | لف | /luf/ | wrap (command) |
| q | وقّت | /waqːata/ | timed | وقت | /waqt/ | time |
| k | أكّل | /ʔakːala/ | fed | أكل | /ʔakala/ | ate |
| l | اللّمس | /ʔlːams/ | the touch | لمس | /lams/ | touch |
| m | نمّام | /namːaːm/ | person who spreads scandals | سمع | /samaʕ/ | heard |
| n | النّمر | /ʔanːimr/ | the tiger | نمر | /nimr/ | tiger |
| h | وهّم | /wahːam/ | puzzled somebody | وهم | /wahm/ | assumed |
| w | توّاب | /tawːab/ | repentant; remorseful; regretful | مواد | /mawaːd/ | material |
| j | أيّد | /ʔajːad/ | supported | يد | /jad/ | hand |

TABLE XXIII. Minimal Vowel Pairs

| Contrastive Phones | | Shared Property | Minimal Pair / Near-Minimal Pair | | |
|---|---|---|---|---|---|
| Phone 1 | Phone 2 | | Word | IPA | Gloss |
| /i:/ | /u:/ | vowel - high | فُول | [fu:l] | type of Levantine bean dish |
| | | | فِيل | [fi:l] | elephant |
| /i/ | /a/ | vowel - front | أُمَّك | [ʔum:ak] | your mother - 'to male' |
| | | | أُمِّك | [ʔum:ik] | your mother - 'to female' |
| /i:/ | /a:/ | vowel - front - long | قِيل | [qi:l] | it was said |
| | | | قَال | [qa:l] | he said |
| /i:/ | /u/ | vowel - high | قِيل | [qi:l] | it was said |
| | | | قُل | [qul] | say 'command' |

TABLE XXIV. Minimal Pairs to Show that Long and Short Vowels are Contrastive

| Contrastive Phones | | Minimal Pair / Near-Minimal Pair | | |
|---|---|---|---|---|
| Phone 1 | Phone 2 | Word | IPA | Gloss |
| /i:/ | /i/ | فيل | /fi:l/ | elephant |
| | | فلم | /film/ | movie |
| /a:/ | /a/ | بادر | /ba:dara/ | took initiative |
| | | بدر | /badr/ | full moon |
| /u:/ | /u/ | ثوم | /θu:m/ | garlic |
| | | ثمّ | /θum:a/ | then |

Supplement 2: Finite-state Machines for Linguistics

### A  AUTOMATA HIERARCHY AND POWER

In comparison to other automata, finite-state machines (FSMs) have the least computing power beyond finite languages and can process regular expressions. More powerful complex automata and languages are push-down automata for context-free languages; embedded push-down automata for mildly context-sensitive (linear indexed) language; nested stack automata for indexed language; linear bounded automata for context-sensitive language; always halting Turing automata for recursive language; and the Turing machine for recursively enumerable language (all formal languages). Fig. 6 illustrates the hierarchy of formal languages (32).
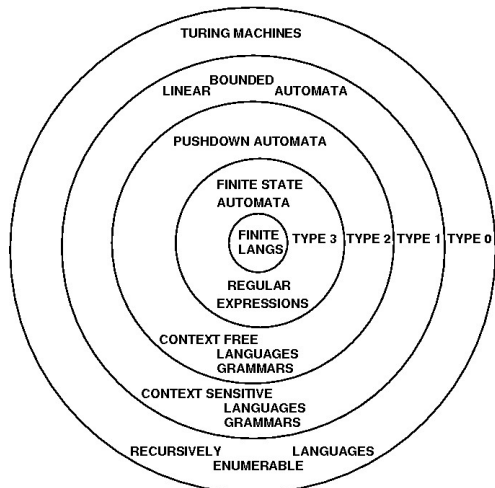


Fig. 6. Formal languages and associated automata; https://www.cs.rochester.edu.

### B  DEVELOPMENT FSM AND COMPILATION TOOLS

Finite-State Machines (FSMs) are either finite-state automata (FSA), which are acceptors of strings constructed to define sets of characters, or finite-state transducers (FSTs), which convert an input string into an output string using contextual or non-contextual replacement, insertion, or deletion. FSAs and FSTs are written using regular expressions and are closed under operations such as concatenation and union. FST is bidirectional and hence input and output can be inverted for the same FST.

The author in (33) constructed cascaded FSTs, with an FST mapping one character at a time between input and output. (34) developed an FST in which the rules were executed in parallel and obligatory or optional single-character mapping rules were allowed. This approach was implemented in various systems such as KIMMO and PC-KIMMO (35; 21; 20).

Bear introduced a unification-based grammar for morphotactic parsing and used diacritics coded in lexical entries to allow the rules to apply to a subset of the lexicon (36; 37). This formalism was adapted by various implementations, which allowed a rule to map between equal-sized input and output string subsequences rather than single characters (38; 39; 40; 41; 42).

Ruessink's formalism allows unequal size sequences and explicit contexts; however, this results in some invalid combina-

tions (43). Pullman and Hepple extended Ruessink's formalism by adding rule features; however, their proposal had problems with the interpretation of obligatory rules. Carter suggested that Pullman and Hepple's formalism was impractical for specifying the mappings between unequal-length sequences (44). Grimley-Evans, Kiraz, and Pulma redefined the obligatory rules in Ruessink's formalism (45).

Algorithms exist for the compilation of rules written as regular expressions into automata (33). Computationally, parsers and compilers for regular expressions are O(n), where n is the length of the input string. Widely available FST compiler tools include Lex, Flex, xfst from Xerox, HFST, Foma, and OpenFST. Foma (4) is an open-source library for unweighted FSTs that has an interface similar to the proprietary XFST from Xerox. OpenFST is suitable for dealing with weighted transducers and has been considered a better tool than the FSM Library of AT&T. In addition, more powerful automata are available in the Natural Language Toolkit (46).

### C  FST FOR COMPUTATIONAL LINGUISTICS

A finite-state transducer (FST) can model most phonological rules, possibly with exceptions related to some stress and tone rules (47), which has been independently verified by (33) (21; 48). Many finite-state models are also available for phonology (49). Cascade and other extensions of finite-state technology are also available (50).

An important FST class is a two-level finite-state formalism that allows the mapping rules between input and output strings to be implemented with finite-state transducers. The same automaton can be used for analysis (decomposition) and synthesis (generation), thereby providing bidirectionality. The two-level formalism and its generalization to multi-levels are used for the phonological analyzer and the concatenative and templatic morphology analyzer.

### D  MULTI-LEVEL FINITE-STATE FORMALISM

(51) described a root-and-pattern morphology FST. (35) proposed a two-level system for language morphology. (52) proposed a framework in which each of the autosegmental tiers was assigned a tape in a multitape finite-state machine, with an additional tape for the surface form. Kay's approach followed the CV model and used four-tape automata, which was an extension of the traditional FST. (52) also proposed a framework for handling templatic morphology in which each templatic morpheme was assigned a tape in a multitape finite-state machine and an additional tape for the surface form.

The two-level formalism has been extended to multiple levels, as illustrated in Fig. 7, in which the templatic morphemes are roots, patterns, and vocalisms. The vocalism morpheme specifies the short vowels to use with a pattern; in contrast, traditional accounts of Arabic morphology collapse the vocalism into the pattern.

The advancement to templatize morphology was achieved by having multiple inputs (tapes) to the FSTs based on linguistic abstractions of Semitic nonlinear morphology. However, such constructs handle only a subset of Arabic words, such as verbs, nouns, or broken plurals.
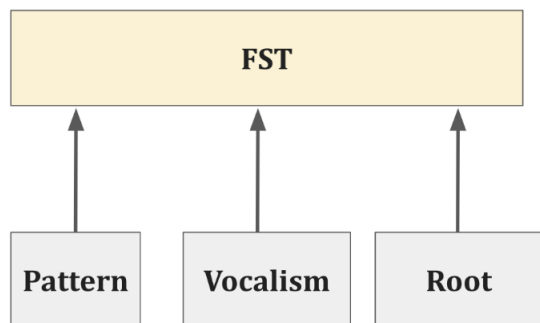
Fig. 7. Three-level FST where the pattern, root, and vocalism are the input tapes.

McCarthy's CV-based model was presented for Arabic morphology under an autosegmental phonology framework to handle verbs (51; 53). A stem is represented by three tiers: the root, vocalism, and a CV pattern. Associations are made based on well-formed conditions, association conventions, and additional rules. The Moraic model uses a different vocabulary to represent the pattern morph based on the noun prosody (54), while the Affixational model derives several templates using affixation under prosodic circumscription for verbs (55).

Infixation and reduplication are handled within the standard two-level morphology using diacritics (20). Kay's approach followed the CV model using a four-tape automaton, which was an extension of the traditional FST (52). (56) used a lexical component that takes the intersection of rules and pattern expressions and produces verbal stems, with the stems being the input for a standard two-level system. (56) also presented a system for handling Akkadian root-and-pattern morphology by adding an additional lexicon component to Koskenniemi's two-level morphology (34). Beesley's intersection approach is probably the largest system for Arabic morphology (57; 39; 58). Beesley later compiled all combinations into a transducer (59).

### E  CONCATENATIVE MORPHOLOGICAL FORMALISM

The state-of-the-art concatenative morphological formalism consists of three components: lexical automata, morphotactic rules, and rewrite rules (60). Finite-state automata are constructed to represent prefixes, stems, and suffixes. The prefix, stem, and suffix are concatenated with markers separating them to form a lexical form based on morphotactic rules that specify valid combinations. Orthographic changes that need to be made to the lexical form to yield the surface form (word) are coded using rewrite rules incorporating contextual mappings and are implemented using an FST.

Morphotactic rules can be implemented in an FST with continuation classes using filters (34; 20; 21). Continuation classes are, however, inappropriate for handling separated dependencies, interdigitation, infixation, and reduplication, and, therefore, flag diacritics are used to address the separated dependencies, discontinuous dependencies, and long-distance dependencies within the FST framework. However, as using FSTs

can be awkward, context-free grammar (with feature unification if necessary) is used to address the complex dependencies (36; 39; 40; 41; 42; 49).

### F  TEMPLATIC MORPHOLOGICAL FORMALISM

(61) embedded pattern and vocalism morphs in the surface expression of the rules, (62) extended the two-level model by adding a third abstract level for inflection patterns, and Kiraz (1994) developed a two-level formalism based on Kay's approach that could handle CV, Moraic, and Affixational models. The first large-scale Arabic morphology implementation within finite-state method constraints, which was conducted by (39), included a 'detouring' mechanism to access multiple lexica, which was the forerunner to other studies by (63). (33) constructed cascading FSTs, in which an FST mapped one character at a time between the input and output. Subsequent advancements in this approach can be found in (63), (50), and (16). Cascade and other extensions of finite-state technology are also available (16). (64) extended Kay's approach and implemented a multi-tape system for MSA.

### G  PHONOLOGY FORMALISM

(65) modeled autosegmental phonology using FSTs, in which the autosegmental phonology was coded as linear strings, (49) used a one-level phonological approach to code autosegmental representations as a triangular prism, and (66) used multilinear coding that was processed using state labeled finite automata, which were shown to be more powerful than FSTs.

### REFERENCES

[1] D. Jurafsky and J. H. Martin, Eds., *Speech and Language Processing: An Introduction to Natural Language Processing, Computational Linguistics, and Speech Recognition*, 2020.

[2] F. Seifart, ``Orthography development,'' *Essentials of language documentation*, pp. 275--299, 2006.

[3] R. Hetzron, Ed., *The Semitic Languages*. Routledge, 1997.

[4] M. Hulden, ``Foma: a finite-state compiler and library,'' in *Proceedings of the Demonstrations Session at EACL 2009*, 2009, pp. 29--32.

[5] N. Halabi, ``Modern standard arabic phonetics for speech synthesis,'' Ph.D. dissertation, University of Southampton, 2016.

[6] T. Zerrouki and A. Balla, ``Tashkeela: Novel corpus of arabic vocalized texts, data for auto-diacritization systems,'' *Data in Brief*, vol. 11, pp. 147 -- 151, 2017.

[7] A. Dahdah and G. M. Abdulmassih, *A dictionary of Arabic grammar in charts and tables*. Librairie du Liban, 1981.

[8] M. b. A. B. Al-Razi, ``Mukhtar al-sihah,'' *Beirut: Dar al-Namudzajiyah*, 1999.

[9] A. El-Dahdah, E. Matar, and G. M. Abdul-Massih, ``majam qawaaid al-arabiiat al-aalamiiat (a dictionary of universal arabic grammar)/معجم قواعد العربية العالمية,'' 1990.

[10] A. Pasha, M. Al-Badrashiny, M. T. Diab, A. El Kholy, R. Eskander, N. Habash, M. Pooleery, O. Rambow, and R. Roth, ``Madamira: A fast, comprehensive tool for morphological analysis and disambiguation of arabic.'' in *Lrec*, vol. 14, no. 2014, 2014, pp. 1094--1101.

[11] K. R. Beesley, ``Finite-state morphological analysis and generation of arabic at xerox research: Status and plans in 2001,'' in *ACL Workshop on Arabic Language Processing: Status and Perspective*, vol. 1. Citeseer, 2001, pp. 1--8.

[12] N. Y. Habash and O. C. Rambow, ``Magead: A morphological analyzer and generator for the arabic dialects,'' 2006.

[13] K. Darwish, M. Diab, and N. Habash, ``Proceedings of the acl workshop on computational approaches to semitic languages,'' in *Proceedings of the ACL Workshop on Computational Approaches to Semitic Languages*, 2005.

[14] M. Attia, P. Pecina, A. Toral, L. Tounsi, and J. van Genabith, ``An open-source finite state morphological transducer for modern standard arabic,'' in *Proceedings of the 9th International Workshop on Finite State Methods and Natural Language Processing*, 2011, pp. 125--133.

[15] K. Darwish, ``Building a shallow arabic morphological analyser in one day,'' in *Proceedings of the ACL-02 workshop on Computational approaches to semitic languages*, 2002.

[16] T. Buckwalter, ``Buckwalter arabic morphological analyzer version 1.0,'' *Linguistic Data Consortium, University of Pennsylvania*, 2002.

[17] D. Graff, M. Maamouri, B. Bouziri, S. Krouna, S. Kulick, and T. Buckwalter, ``Standard arabic morphological analyzer (sama),'' *Linguistic Data Consortium LDC2009E73*, 2010.

[18] O. Smrz, ``Elixirfm--implementation of functional arabic morphology,'' in *Proceedings of the 2007 workshop on computational approaches to Semitic languages: common issues and resources*, 2007, pp. 1--8.

[19] R. Roth, O. Rambow, N. Y. Habash, M. Diab, and C. Rudin, ``Arabic morphological tagging, diacritization, and lemmatization using lexeme models and feature ranking,'' 2008.

[20] E. L. Antworth, ``Pc-kimmo: a two-level processor for morphological analysis,'' *Summer Institute of Linguistics*, 1990.

[21] L. Karttunen, *Finite-state lexicon compiler*. Xerox Corporation, Palo Alto Research Center, 1993.

[22] G. Kiraz, ``Multi-tape two-level morphology: a case study in semitic non-linear morphology,'' *arXiv preprint cmp-lg/9407023*, 1994.

[23] M. Mohri, F. Pereira, and M. Riley, ``Weighted finite-state transducers in speech recognition,'' *Computer Speech Language*, vol. 16, no. 1, pp. 69--88, 2002. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0885230801901846

[24] M. T. Diab, ``Second generation amira tools for arabic processing : Fast and robust tokenization , pos tagging , and base phrase chunking,'' 2009.

[25] A. A. Al-Nassir, ``Sibawayh the phonologist: A critical study of the phonetic and phonological theory of sibawayh as presented in his treatise? al kitab?'' Ph.D. dissertation, University of York, 1985.

[26] Y. A. El-Imam, ``Phonetization of arabic: rules and algorithms,'' *Computer Speech & Language*, vol. 18, no. 4, pp. 339--373, 2004.

[27] F. Biadsy, N. Habash, and J. Hirschberg, ``Improving the arabic pronunciation dictionary for phone and word recognition with linguistically-based pronunciation rules,'' in *Proceedings of human language technologies: The 2009 annual conference of the North American chapter of the association for computational linguistics*, 2009, pp. 397--405.

[28] A. Ramsay, I. Alsharhan, and H. Ahmed, ``Generation of a phonetic transcription for modern standard arabic: A knowledge-based model,'' *Computer Speech & Language*, vol. 28, no. 4, pp. 959--978, 2014.

[29] M. Maamouri, A. Bies, T. Buckwalter, and W. Mekki, ``The penn arabic treebank: Building a large-scale annotated arabic corpus,'' in *NEMLAR conference on Arabic language resources and tools*, vol. 27. Cairo, 2004, pp. 466--467.

[30] J. Åkesson, ``Arabic morphology and phonology: Based on the marāḥ al-arwāḥ by aḥmad b.'aī b. mas 'ūd,'' in *Arabic Morphology and Phonology*. Brill, 2017.

[31] A. A. S. Farghaly, ``Arabic computational linguistics,'' *(No Title)*, 2010.

[32] M. Sipser, *Introduction to the Theory of Computation*. Cengage Learning, 2012.

[33] R. M. Kaplan and M. Kay, ``Regular models of phonological rule systems,'' *Computational linguistics*, vol. 20, no. 3, pp. 331--378, 1994.

[34] K. Koskenniemi, ``Two-level morphology,'' Ph.D. dissertation, Ph. D. thesis, University of Helsinki, 1983.

[35] L. Karttunen *et al.*, ``Kimmo: a general morphological processor,'' in *Texas Linguistic Forum*, vol. 22. Texas, USA, 1983, pp. 163--186.

[36] J. Bear, ``A morphological recognizer with syntactic and phonological rules,'' in *COLING*, vol. 86, no. 10.3115, 1986, pp. 991 365--991 445.

[37] ------, ``Morphology with two-level rules and negative rule features,'' in *Coling Budapest 1988 Volume 1: International Conference on Computational Linguistics*, 1988.

[38] A. W. Black, G. Ritchie, S. Pulman, and G. Russell, ``Formalisms for morphographemic description,'' in *Third Conference of the European Chapter of the Association for Computational Linguistics*, 1987.

[39] K. Beesley, T. Buckwalter, and S. Newton, ``Two-level finite-state analysis of arabic morphology,'' in *Proceedings of the Seminar on Bilingual Computing in Arabic and English*, 1989, pp. 6--7.

[40] H. Trost, ``The application of two-level morphology to non-concatenative german morphology,'' 1990.

[41] G. D. Ritchie, *Computational morphology: practical mechanisms for the English lexicon*. MIT press, 1992.

[42] E. L. Antworth, ``Morphological parsing with a unification-based word grammar,'' in *Proceedings of the North Texas Natural Language Processing Workshop*. Citeseer, 1994, pp. 24--32.

[43] H. Ruessink, *Two-level formalisms*. Katholieke Universiteit, 1989.

[44] D. Carter, ``Rapid development of morphological descriptions for full language processing systems,'' *arXiv preprint cmp-lg/9502006*, 1995.

[45] E. Grimley-Evans, G. A. Kiraz, and S. G. Pulman, ``Compiling a partition-based two-level formalism,'' *arXiv preprint cmp-lg/9605001*, 1996.

[46] S. Bird, E. Klein, and E. Loper, *Natural language processing with Python: analyzing text with the natural language toolkit*. " O'Reilly Media, Inc.", 2009.

[47] C. D. Johnson, *Formal aspects of phonological description*. Walter de Gruyter GmbH & Co KG, 2019, vol. 3.

[48] K. R. Beesley and L. Karttunen, ``Finite-state morphology:

Xerox tools and techniques," *CSLI, Stanford*, pp. 359--375, 2003.

[49] S. Bird and T. M. Ellison, ``One-level phonology: Autosegmental representations and rules as finite automata," *Computational Linguistics*, vol. 20, no. 1, pp. 55--90, 1994.

[50] K. R. Beesley and L. Karttunen, ``Finite-state nonconcatenative morphotactics," *arXiv preprint cs/0006044*, 2000.

[51] J. J. McCarthy, ``A prosodic theory of nonconcatenative morphology," *Linguistic inquiry*, vol. 12, no. 3, pp. 373--418, 1981.

[52] M. Kay, ``Nonconcatenative finite-state morphology," in *Third Conference of the European Chapter of the Association for Computational Linguistics*, 1987.

[53] J. A. Goldsmith, *Autosegmental and metrical phonology*. Basil Blackwell Cambridge, 1990, vol. 1.

[54] J. McCarthy and A. Prince, ``Prosodic morphology and templatic morphology," in *Perspectives on Arabic linguistics II: papers from the second annual symposium on Arabic linguistics*. John Benjamins Pub. Co. Amsterdam, 1990, pp. 1--54.

[55] J. J. McCarthy and A. Prince, ``Generalized alignment," in *Yearbook of morphology 1993*. Springer, 1993, pp. 79--153.

[56] L. Kataja and K. Koskenniemi, ``Finite-state description of semitic morphology: A case study of ancient accadian," in *Coling Budapest 1988 Volume 1: International Conference on Computational Linguistics*, 1988.

[57] K. Beesley, ``Finite-state description of arabic morphol-ogy," in *Proceedings of the Second Cambridge Conference: Bilingual Computing in Arabic and English*, 1990, pp. 5--7.

[58] K. R. Beesley, ``Computer analysis of arabic morphology: A two-level approach with detours," in *Perspectives on Arabic Linguistics III: Papers from the Third Annual Symposium on Arabic Linguistics*. John Benjamin's Publishing Company Amsterdam, 1991, pp. 155--172.

[59] ------, ``Arabic finite-state morphological analysis and generation," in *COLING 1996 Volume 1: The 16th International Conference on Computational Linguistics*, 1996.

[60] R. W. Sproat, *Morphology and computation*. MIT press, 1992.

[61] S. G. Pulman and M. R. Hepple, ``A feature-based formalism for two-level phonology: a description and implementation," *Computer Speech & Language*, vol. 7, no. 4, pp. 333--358, 1993.

[62] A. Narayanan and L. Hashem, ``On abstract finite-state morphology," in *Conference of the European Chapter of the Association for Computational Linguistics*, 1993.

[63] K. R. Beesley, ``Arabic morphology using only finite-state operations," in *SEMITIC@COLING*, 1998.

[64] G. A. Kiraz, ``Multitiered nonlinear morphology using multitape finite automata: a case study on syriac and arabic," *Computational Linguistics*, vol. 26, pp. 77--105, 2000.

[65] A. Kornai, ``Formal phonology," 2018.

[66] B. Wiebe, ``Modelling autosegmental phonology with multi-tape finite state transducers," 1992.

# Applications of Artificial Intelligence for Information Diffusion Prediction: Regression-based Key Features Models

Majed Algarni*, Mohamed Maher Ben Ismail

King Saud University, College of Computer and Information Sciences
Department of Computer Science, Saudi Arabia

*Abstract*—Information diffusion prediction is essential in marketing, advertising, and public health. Public health officials may avoid disease outbreaks, and businesses can optimize marketing campaigns and target audiences. Information diffusion prediction helps identify influential nodes in social networks, enabling targeted interventions to spread positive messages or counter misinformation. Organizations can make informed decisions and improve society by analyzing information propagation patterns. This research study investigates the prediction of information diffusion on social media platforms using a diverse set of features and advanced machine learning and deep learning models. We explore the impact of network structure, early retweet dynamics, and tweet content on social media, provided by the publicly available dataset Weibo, a social network like Twitter. By applying the training of the models on set of features separately, we observed different performances. The Random Forest model using all features achieved an R-squared of 76.690%. The Random Forest (RF) model focusing on the following network structure achieved an R-squared of 90.773%. The RF model analyzing the retweeting network structure achieved an R-squared of 98.161%.

*Keywords—Information diffusion; social media data; machine learning; deep learning*

## I. INTRODUCTION

In our current digital age, the number of Internet users has increased, which has been accompanied by an increase in the number of users of social media. This was reflected significantly in the speed of exchanging and sharing information through social media platforms. Information is divided by its nature into useful and harmful, directly affecting society in economic, political and commercial terms [1]. The dissemination of this information can be studied and predicted in terms of and is affected by many variables, such as the timing of the publication [2], as well as the content of the publication, and the characteristics of the participating users [3,4]. A comprehensive understanding of the dynamics of information spread on social media platforms can provide valuable insights in various domains, including marketing, disaster management, and community detection. The dissemination of information via social media is a multifaceted process that relies not only on the substance of the communicated content but also on the method of transmission. The comprehension of the mechanisms by which information is conveyed through these networks is progressively imperative due to the escalating migration of various aspects of our

existence to online platforms. The spread of information through social media sites like Twitter and Facebook has greatly impacted. The study of how information spreads on these platforms is complex and constantly changing, which is why it's attracted so much attention from researchers. By understanding how information spreads, we can predict how popular information will become, maximize the influence spread, and monitor how cascades develop. On Twitter, users can "retweet" or share a tweet with their followers, which helps information spread even faster. The Popularity of a tweet is measured by its content and how many times it's been retweeted. By understanding how information spreads on social media, platforms can better monitor and guide the spread of information in different scenarios like online advertising, viral marketing, and fake news detection. Several approaches to predicting information diffusion exist but machine learning and deep learning techniques [5, 6] have recently shown much promise.

In this study, the authors proposed Machine learning and deep learning models to improve our forecasts using a publicly available dataset provided by authors in [7]. This dataset was collected from Weibo, a social network like Twitter. The authors applied the models to features such as following network structure, retweeting network structure, early-stage popularity dynamics, and tweet content. Our study offers significant contributions to the domain of predicting information diffusion on social media platforms.

*1) Comprehensive examination:* Our study delves into the dissemination of information on social media platforms through the utilization of an extensive array of features and sophisticated machine learning and deep learning models.

*2) An examination of essential factors for comprehension:* In this study, we investigate the influence of network structure, early retweet dynamics, and tweet content on information diffusion. Through our analysis, we aim to gain valuable insights into the underlying factors that contribute to information propagation.

*3) Model performance:* The models trained using distinct sets of features in order to evaluate their performance. The RF model based on all features demonstrated an R-squared value of 76.690%, whereas the model that specifically targeted the indicated network structure exhibited an R-squared value of 90.773%. The RF model utilized for analyzing the retweeting

*Corresponding Author.

network structure exhibited a high R-squared value of 98.161%.

*4) Real-world applications:* It refers to the practical utilization of knowledge, theories, and concepts in various fields. These applications involve The results of our study have the potential to assist the organizations in enhancing their decision-making processes, contribute to societal improvement by facilitating comprehension of information diffusion, and enable the identification of influential individuals within social networks for the purpose of implementing targeted interventions. The aforementioned findings carry significant ramifications for the fields of marketing, advertising, and public health. The remains sections of this research article are as follows: a comprehensive review of related work in Section II, followed by the methodology in Section III. Section IV delves into evaluation metrics. Experimental results, discussion, and conclusion in Section V, Section VI and Section VII respectively.

## II. RELATED WORK

### A. Background of the Information Diffusion

Sharing content on social media platforms like Twitter and Facebook spreads information. Social media is about sharing content. Businesses, advertisers, and marketers should address this important issue. They may effectively communicate with their target audience, strategically advertise their products and services, and remain competitive. Social media is crucial for marketing. Companies can grow their market and build client relationships [8]. Commercial organizations can improve their business strategies, increasing their expertise in efficiently spreading their message and news, and leverage social media platforms to amplify their brand by researching information dissemination that helps promote their products and services further in this section. In information diffusion, there are three main elements Sender, Receiver, and Medium, as shown in Fig. 1. The sender, whether an individual or a group, initiates the dispersion process. They are the ones who are in charge of spreading the information that needs to be spread. The receiver, or group of receivers, denotes the individuals who have received the information that has been spread. The process of dispersion generally has a wider scope of influence, as evidenced by the fact that the number of receivers usually be more than the number of senders. The medium is the way information about diffusion travels from sender to receiver. There are many communication channels for information spreading such as TV, newspapers, and social media platforms like Twitter. Additionally, personal connections play a dynamic role in communication. Furthermore, factors such as airborne diseases can also impact the way information is disseminated. Understanding diffusion is crucial process. It shows us how information spreads and changes behavior in a system. Researchers can study the sender-receiver relationship and the medium used. This helps them learn about diffusion and find ways to manage and control it.

### B. Literature Review

Twitter has become a powerful tool for spreading information. People can share information with followers and beyond through retweets, posts, and hashtags. Various research studies have observed what makes people retweet and how information spreads on these networks. Factors can include the tweet's content, the source of the information, emotional appeal, timing, and social influence. Researchers found Twitter as a way to study diffusion patterns and how different factors affect information spread. But knowing how information spreads efficiently on Twitter is still a challenge. Machine learning and deep learning techniques are being used to analyse and predict diffusion patterns on Twitter. These techniques can find hidden patterns in large datasets. They can help us understand what drives information to spread.

The Research domain of information diffusion on Twitter has a variety of approaches. Study conducted by authors [9] aimed to determine the characteristics that predict the level of engagement a tweet receives. The findings suggest that tweets with positive sentiment and positive arousal receive more retweets and favourites, although the effect size is small. Predicting information diffusion has been another focal point of research. A study by authors in [10] suggest that modelled tweet popularity as the number of retweets and developed machine learning models predict the same, achieving an accuracy of up to 60% and an F1 score of 67%. Another researcher proposed approach to predict information diffusion based on user-based, time-based, and content-based features, resulting in a model that improves the F-measure by about 5% compared to the state-of-the-art Masud et al. Authors in [5] in their study Twitter hate speech based-on topics. The researchers analyze a massive collection of tweets, retweets, user activity logs, and follower networks. They also collect online news stories. The authors provide feature-rich methods for predicting hashtag-related hate speech. The best model scored 0.65 macro F1. RETINA, a neural network for Twitter retweet prediction, is also presented. This design has a macro F1-score of 0.85. Their study sheds light on how Twitter users start hate speech and spread it through retweets. Authors in study [11], introduce an approach for predicting the spread of information prompted by a Twitter user's tweet. They leverage six user features, like number of followers and tweet frequency, along with 80 linguistic and psychological aspects provided by the Linguistic Inquiry and Word Count (LIWC) software. Their approach comprises a module that formulates regular basic tweet propagation patterns and a classifier that anticipates the tweet pattern associated with a specific user tweet. The study uses Tree-Shaped Tweet Cascades for the dataset, achieving significant accuracy in predictions, notably an F-measure of 0.89 with the JRIP model.
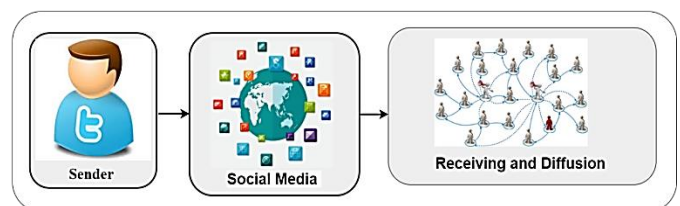


Fig. 1. Demonstrating the information diffusion process on social media.

The propagation on Twitter is the current problem, with a particular emphasis on influence and prediction. The authors of [3] examine Twitter's information diffusion model, which sees the spread of information on the platform as a problem with several variables over time. It focuses on tweet quantity, emotional tone, and influence. Time series clustering reveals Twitter information transmission patterns. The study clusters hashtags with similar patterns using time series clustering methods. This study forecasts three-dimensional parameters using Autoregressive Integrated Moving Average and LSTM linear and non-linear time series models. LSTM models attained an accuracy of 80%.

Previous studies have directed their attention towards more granular facets of information dissemination on the Twitter platform. The study proposed an information diffusion model that conceptualized information diffusion as a problem of multivariate time series analysis. This model specifically addressed the variables of tweet volume, tweet sentiment, and tweet influence [12]. In their study, the authors introduced an algorithm named SentiDiff, which integrates textual data and sentiment diffusion patterns to effectively forecast sentiment polarities conveyed in Twitter messages. The algorithm that has been suggested demonstrates improvements in PR-AUC, ranging from 5.09% to 8.38% for classification tasks, in comparison to existing sentiment analysis algorithms that rely on textual information [12, 13].

Other approaches are based on the anticipated graph information diffusion node activations; the Topological Recurrent Neural Network (Topo-LSTM) was introduced in [14]. Diffusion topologies are used to characterize the cascade structure. This DAG model depicts the cascade. The Topo-LSTM is a diffusion-prediction-specific LSTM architecture. A MAP increases from 20.1% to 56.6%. The researchers found that using dynamic directed acyclic graphs (DAGs) with the innovative data model and Topo-LSTM architecture improves diffusion structure representation.

Authors in [15] presented a model that predicts how information flows on Twitter. The model learns the probability of influence between users. It considers both time-based and structural aspects of influence spread. The effectiveness of the suggested models is examined on two datasets, Darwin and MelCup17. The TDD-CP model achieved a balanced precision of 94.64% and a recall of 95.9% on the Darwin dataset. The MelCup17 dataset achieved a balanced precision of 95.13% and a recall of 98.2Authors in the study [16] developed a Twitter information spread model. To improve predictions, the model has used custom-weighted word characteristics. A Custom Weighted Word Embedding is proposed to measure content diffusion via retweets. Twitter postings are used to extract lexical units, build a matrix with word sequences, and apply specific weights based on the sentence's presence index. Long Short-Term Memory (LSTM) and Convolutional Neural Networks (CNN) are used to predict information dissemination and improve accuracy and training time. The CWWE framework improves the deep learning framework model accuracy, according to experiments. The researchers collected 230,000 tweets from over 45,000 users over six months. Model accuracy increased from 53% to 80%. The authors in [32] introduced the LARM (Lifetime Aware Regression Model), a

ground-breaking method for tackling the problem of online content popularity long-term prediction in dynamic YouTube networks. One way that LARM sets itself apart is by considering content longevity as a significant aspect, which helps to mitigate the drawbacks that come with a large amount of historical data and inappropriate model assumptions. The model exhibits flexibility to different observation intervals and is fitted using a forecast lifetime metric that is derived from early-accessible variables. The varied lives of video content are accommodated by specialized regression models. Based on two YouTube datasets, the experimental findings demonstrated the significant advantage of LARM, with prediction error reductions of up to 20% and 18%, respectively.

Despite the considerable body of research that has been conducted on the phenomenon of information diffusion on the social media platform Twitter, there remains a notable gap in the existing literature that necessitates further investigation and exploration. The authors in [34] explored the intricacies of information dissemination on social media, focusing on the Sina microblog controversy around the L group Double 11 fraudulent advertising incidents. Using a strong data analytics methodology that combines time series regression and data mining, the study reveals the key variables influencing the dissemination of information. User activity, emotional shifts, and media attention have been recognized as important drivers, with sentiment polarity and reposting being critical factors in various dissemination phases.

The area of utilizing the number of retweets and retweeted counts, in combination with advanced machine learning techniques, is currently lacking in comprehensive exploration. The comprehension and anticipation of diverse aspects of information diffusion, encompassing the factors that impact the dissemination of information and the dynamics of diffusion patterns, constitute significant areas of scholarly inquiry that merit consideration. This study addresses the identified research gap by proposing using machine learning and deep learning models. Through utilizing these models, significant insights can be obtained regarding the intricacies of information dissemination on the social media platform Twitter. This research endeavor aims to augment our comprehension of the mechanisms through which information propagates on social media platforms. This pursuit aims to establish a basis for enhanced prediction and awareness of the intricate dynamics of disseminating information.

## III. METHODOLOGY

This study proposed a methodology for predicting information diffusion in social media based on retweets and retweeted counts. Deep learning and machine learning techniques are used to predict information dissemination. The methodology involves data preparation and training models on large-scale social media datasets. The choice of the features and the proposed framework used in our study was a carefully considered process aimed at comprehensively understanding social media information diffusion. The elected features, such as Following Network Structure (FNet), Retweeting Network Structure (RNet), and Early Popularity (early), were strategically picked to capture dissimilar dimensions of the

diffusion phenomenon. The proposed framework of the information diffusion prediction is demonstrated in Fig. 2.
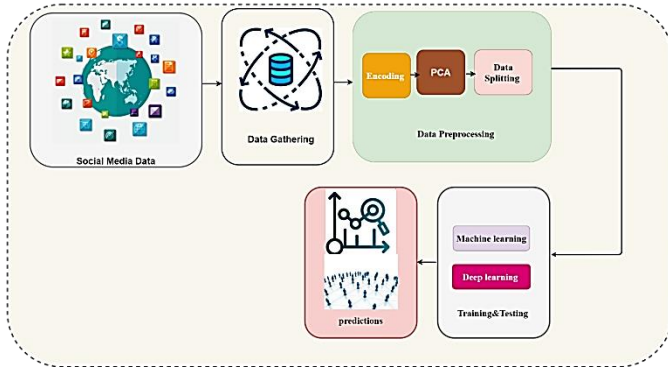


Fig. 2. The proposed framework for information diffusion prediction.

### A. Data Source

Sina Weibo is a popular social network site like Twitter. We used a large dataset from Sina Weibo [7] for our research. The dataset provides by DataCastle. It has 30,010 original tweets. Each tweet has its own ID. The ID has information like the user's ID, the time the tweet was posted, and the tweet's content. The tweets were posted between January 1, 2015 and May 20, 2016. This dataset was developed by authors in [7]. It is publicly available online. The dataset is large, so we can study how information spreads on Weibo. We can learn more about predicting information cascade scales based on analyzing set of features.

### B. Feature Extraction

The dataset developers categorized data features into four groups: following network structure, retweeting network structure, early-stage popularity dynamics, and tweet content. We aim to capture various aspects of information diffusion dynamics by extracting and incorporating these features.

*1) Following network structure:* The following network structure plays a crucial role in information diffusion. The constructs a network (G_F) based on the relationships among users who follow each other. Five network structural features are derived from measuring user influence in this network, including out_degree_F, in_degree_F, all_degree_F, bi_degree_F, and pagerank_F, as described in Table I [7].

*2) Retweeting network structure:* Retweeting is a key mechanism for information diffusion. The builds a retweeting network (G_R) using retweet data from the first 60 minutes. Similar to the following network, by extracts five network structural features to quantify user influence in the retweeting network: out_degree_R, in_degree_R, all_degree_R, bi_degree_R, and pagerank_R, as described in Table I [7].

*3) Early retweet dynamics:* The early-stage retweet time series contains valuable temporal information. We construct four types of temporal features to capture trends and fluctuations in cascade sizes over time. These features include cascade (cumulative cascade sizes in one minute intervals), burstiness (measuring the burst of popularity), stability

(assessing the stability of Popularity), and release_time (hour of original tweet release), as described in Table I [7].

*4) Tweet content:* The initial tweets' content also plays a role in how the information spreads. To get feature vectors out of the tweet content, the dataset developers [18] used the word frequency-inverse document frequency algorithm. In addition, they get topic distributions using the latent Dirichlet allocation (LDA) topic model. Contentgory (themes category), wordlength (text length), URL presence, hashtag presence, photo presence, and mention presence are the six features retrieved from tweet content, as described in Table I [7].

TABLE I. ILLUSTRATES THE FOUR CATEGORIES OF FEATURES USED IN THE PREDICTION OF CASCADES

| Features | Description | Representation |
|---|---|---|
| Following Network Structure (FNet) | The count of individuals who are following the user who made the post. | out_degree_F [7,17,18,19,,20]. |
| | The count of individuals whom the posting user follows. | in_degree_ [7,17,18,19,,20]. |
| | The count of individuals who either follow or are followed by the posting user. | all_degree_F [7]. |
| Following Network Structure (FNet) | The count of individuals who both follow and are followed by the posting user. | bi_degree_F [7] |
| | PageRank centrality in $G_F$ | pagerank_F [7] |
| Retweeting Network Structure (RNet) | The count of individuals who retweet the tweets of the posting user | out_degree_R [7] |
| | The count of individuals who have been retweeted by the posting user | in_degree_R [7] |
| | The count of individuals who either retweet or are retweeted by the posting user | all_degree_R |
| | The count of individuals who both retweet and are retweeted by the posting user | bi_degree_R |
| | PageRank centrality in $G_R$ | pagerank_R [33] |
| Early Popularity (early) | the sizes of cascades during the observation period, divided into intervals of 1 minute | cascade |
| | The measure of how quickly and intensely popularity increases in the early period | burstiness |
| | The measure of how consistent and stable the popularity remains in the early period | stability |
| | The timestamp indicating when the original tweet was posted | Release_time |

### C. Data Pre-processing

A rule-based methodology has been employed to label the dataset to encode the variable 'all_degree2', which signifies the number of retweets and retweeted counts. This study aimed to minimize the level of variability in the chosen variable and enhance the ease of analyzing diffusion patterns. The encoding procedure entailed the categorization of values into three distinct groups: 'low diffusion' (set as '10'), 'medium diffusion' (set as '20'), and 'high diffusion' (set as '30'). The encoding scheme offers a distinct representation of the levels of diffusion linked to the number of retweets and retweeted counts.

Assigning discrete levels to the variable 'all_degree2' enhances comprehensibility and facilitates the analysis of diffusion patterns in the dataset. Fig. 3 represents the retweet counts in the dataset.
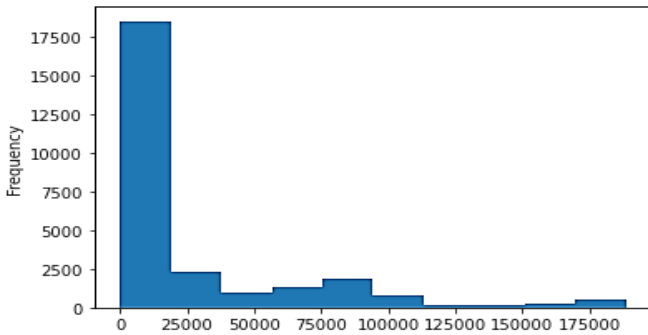


Fig. 3. Representing of the dataset retweet count analysis.

Fig. 4 provides a visual representation of the encoded values, thereby offering valuable insights into the distribution patterns of diffusion levels. This methodology streamlines the inspection of information propagation dynamics and deepens our comprehension of the dataset samples.
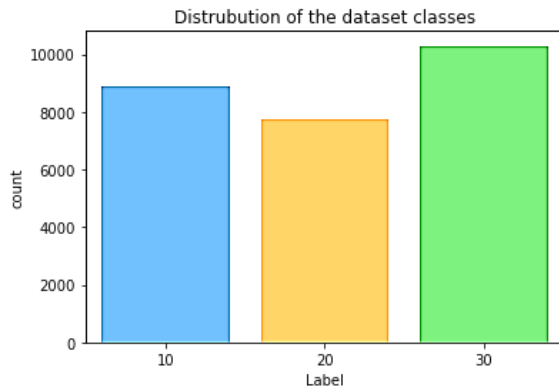


Fig. 4. Show the distribution of the dataset classes.

### D. Data Normalization

In this study, the standard scalar is used on features for predicting information spread on social media. It makes the features have a similar scale values. This helps some machine learning algorithms that are sensitive to the scale of input data. This step makes all features contribute equally to the prediction task at hand. No feature dominates the learning process because of its original scale. The standard scaler calculates the mean and standard deviation of each feature. Then it transforms the values based on these statistics. The scaled features have a mean of zero and a standard deviation of one [21]. Using the standard scaler on this study's features enhances the model's comparability and interpretability. This leads to more accurate predictions and analysis.

### E. Dimensionality Reduction

The Principal Component Analysis (PCA) uses to remove unimportant elements from high-dimensional data to ease interpretation. Dimensionality reduction shortens data analysis and interpretation without sacrificing essential features. A PCA finds the dataset's most variable eigenvectors. PCA selects the most significant eigenvectors while retaining the most variation by reducing data dimensionality. The PCA projects data onto eigenvectors for visualization task. This helps identify data patterns and simplifies multidimensional data. It facilitates complex data, focuses on critical issues, and aids interpretation [22].

### F. Data Split

In research, it is common practice to split the data into training and testing sets, usually using 80:20 ratios. The training set is used to train the model, while the testing set is used to evaluate the model's performance on test data. This split allows researchers to assess how well their models generalize to new, unseen data and make reliable results based on their research findings.

### G. Prediction Models

This subsection details of machine learning and deep learning model architecture to analyze and model information diffusion patterns in social media networks.

*1) Machine learning models:* Machine Learning is a subfield within the realm of artificial intelligence that facilitates the acquisition of knowledge and improvement of systems through experience, thereby enhancing their performance without the need for explicit programming [23]. Regression is a widely employed machine learning methodology that aims to forecast continuous outcomes by utilizing statistical techniques to establish the association between independent and dependent variables.

*a) Linear regression model:* Linear Regression (LR) is a Statistical analysis method. This analysis considers several independent factors and one dependent variable and the relations between them [24]. The LR technique can help one understand how social media spreads information. In study of RL analysis for information dissemination, dependent variable is information dispersion or an analogous indicator like retweets or post spread. Independent variables include content features, network design, and other external factors that may affect content transmission. Fitting a linear regression model to the data estimates the coefficients for each independent variable. They control the variable. This model assumes a linear relationship between characteristics and diffusion strength. Linear regression helps us understand how features affect diffusion levels. Positive coefficients mean an increase in the feature leads to an increase in diffusion. Negative coefficients mean the opposite. The intercept shows the baseline diffusion when all features are zero, giving us insight into the content's inherent diffusion capacity.

*b) Random forest regressor model:* The Random Forest Regressor (RFR), a machine learning technique, is well-suited for modelling information diffusion. It predicts information dissemination by averaging the results of several decision trees. This prediction aggregation reduces variance, improving the model's test set generalization [25]. The RFR model can handle diverse, noisy data because it resists outliers. This is one of the RFR main advantages. It can also discover non-linear data linkages, which helps it produce accurate forecasts

even in challenging settings. It distributes errors evenly across classes to handle unbalanced datasets. The RFR also helps assess the model's numerous variables' relative importance. It assigns significance scores to qualities, indicating their relevance to the prediction task. This knowledge can help researchers comprehend information spread factors.

*2) Deep learning models:* CNNs and RNNs can be used to model how information spreads through social networks and communication channels. CNNs can identify important elements or patterns that spread information by extracting relevant textual or visual input features. The ANN, BiLSTM [26], and GRUs models can sequential data well for temporal information diffusion analysis. These architectures can identify critical diffusion nodes and anticipate future spread by capturing relationships and patterns in interaction or event sequences. Deep learning approaches can help to predict, analyse, and intervene in information diffusion by revealing its mechanisms and dynamics.

*a) The ANN Model:* In this study, ANN Regression has been proposed for information diffusion prediction in online social media. This sequential regression neural network model architecture consists of the input, output and hidden layers [27]. The input data passed to two hidden layers with 64 units with rectified linear unit (ReLU) activation function. Those layers can capture non-linear relationships and complex patterns present in the data. The model's output is a single unit for predicting the continuous variables related to information diffusion. The model Parameter describes in Table II.

TABLE II. THE ANN USED PARAMETERS

| Parameter | Dilates |
|---|---|
| Input Shape | (4, 1) |
| Input Dimensions | Input shape |
| Hidden Layers | 2 |
| Output Units | 1 |
| Optimizer | Adam |
| Epochs | 100 |

The mean squared error (MSE) has been used to measure the average squared difference between predicted and actual values. The Adam optimizer dynamically adjusts the learning rate based on the gradients' first and second moments to update the model's weights. MSE and MAE are used to evaluate model performance. These metrics reveal the model's accuracy and precision, helping researchers assess its ability to predict information diffusion patterns in online social media.

*b) CNN-BiLSTM Model:* This paper introduces a neural network model designed to predict information diffusion on online social media platforms. The model was constructed utilizing the Keras library and incorporates a range of components designed to effectively capture complex patterns and dynamics associated with information propagation. The architecture has proposed adheres to a sequential structure, wherein each component has been meticulously considered. The initial stage involves utilizing one-dimensional

convolutional layer (Conv1D) comprising ten filters and a kernel size of 3. The function of this particular layer is to detect and analyze localized patterns and connections within the given input data. This process aids in identifying and extracting significant features associated with the diffusion of information. To avoid the overfitting issue, a dropout layer is incorporated into the model architecture, wherein a random selection of 20% of the input units are dropped or deactivated during the training process. The utilization of this regularization technique facilitates the process of generalization and diminishes dependence on particular features, thereby enhancing the resilience of diffusion predictions. Subsequently, a bidirectional Long Short-Term Memory (LSTM) layer [26], consisting of 10 units, is incorporated. Long Short-Term Memory (LSTM) networks demonstrate exceptional performance in modeling sequential data and effectively capturing temporal dependencies. The model's bidirectional characteristic enables it to consider both preceding and subsequent time steps, thereby facilitating a holistic comprehension of diffusion dynamics.

Two dense layers follow the LSTM layer. The first dense layer consists of 10 units with the rectified linear unit (ReLU) activation function, enabling the extraction of higher-level features. The second dense layer, with a single unit, generates the final diffusion predictions. To prepare the output for the dense layer, a flatten layer is added, reshaping the preceding layer's output into a one-dimensional vector. The model Parameter describes in the Table III. The evaluation metrics, such as MSE and mean absolute error (MAE), were used to assess the model's performance in accurately predicting the diffusion patterns.

TABLE III. SUMMARIZING OF THE CNN-BILSTM PARAMETERS

| Parameter | Dilates |
|---|---|
| Input Shape | (4, 1) |
| Convolutional Layer | Filters: 10, Kernel Size: 3 |
| Padding | Same |
| Activation Function | ReLU |
| Dropout Rate | 0.2 |
| Bidirectional LSTM Layer | Units: 10, Dropout: 0.3, Recurrent Dropout: 0.3 |
| Dense Layer 1 | Units: 10, Activation Function: ReLU |
| Flatten Layer | - |
| Dense Layer 2 | Units: 1 |
| Loss Function | Mean Squared Error (MSE) |

*c) CNN-GRU Model:* In this study, the CNN-GRU deep learning model architecture uses to predict information diffusion in social media platforms. We define a sequential model to build linear information diffusion. The model consists of one-dimensional convolutional layer employs 10 filters and a kernel size of 3, while utilising the Rectified Linear Unit (ReLU) activation function. This layer is responsible for extracting pertinent features and patterns from the input data to comprehend the information diffusion processes. During training, the dropout layer is employed to randomly deactivate 20% of the input units to mitigate the

overfitting risk. Regularization techniques enhance generalization capabilities of prediction models by reducing feature dependence, thereby increasing their robustness. A Gated Recurrent Unit (GRU) layer follows, consisting of 10 units. This recurrent layer captures temporal dependencies in sequential data, allowing the model to capture the dynamics of information diffusion over time. The model architecture also includes two dense layers. The first dense layer has 10 units with the ReLU activation function, extracting higher-level features. The second dense layer, with a single unit and no activation function, generates the final predictions. The evaluation metrics, such as MSE and mean absolute error (MAE), were used to assess the model's performance in accurately predicting the diffusion patterns. Table IV provides the summarization of the CNN-GRU used parameters.

TABLE IV.    THE CNN-GRU MODEL PARAMETERS

| Parameter | Dilates |
|---|---|
| Input shape | (4,1) |
| Conv1D | Filters: 10, Kernel Size: 3, Padding: 'same' |
| Activation | ReLU |
| Dropout | Rate: 0.2 |
| GRU | Units: 10, Dropout: 0.3, Recurrent Dropout: 0.3 |
| Dense | Units: 10, Activation: ReLU |
| Flatten | - |
| Dense | Units: 1 |
| Optimizer | Adam |

## IV.    EVALUATION METRICS

In this study, the researchers used various fundamental measurement metrics to evaluation the models' performance, including Mean Squared Error (MSE), Mean Absolute Error (MAE), R-squared (R2), and Root Mean Squared Error (RMSE). These metrics function as significant indicators of the accuracy and predictive capabilities of the models, allowing for a precise evaluation and comparison of their performance.

### A. Mean Squared Error (MSE)

The Regression analysis uses MSE to evaluate prediction models. The MSE method calculates the averages of the squared deviations between predicted and actual values. Squaring large deviations makes the MSE more sensitive to outliers [28]. The RF model performs best with a low MSE. The following formula can calculate the MSE [28].

$$MSE = \frac{1}{n}\sum_{i=1}^{n} (y_i - \hat{y}_i)^2 \qquad (1)$$

### B. Root Mean Squared Error (RMSE)

The Root Mean Squared Error (RMSE) is a commonly employed evaluation metric especially for regression analysis. It calculates the square root of the mean of the squared differences between the predicted and actual values [31]. Root Mean Square Error (RMSE) is a statistical metric that quantifies the typical magnitude of errors and indicates the standard deviation of the residuals. This technique proves to be highly advantageous in scenarios where substantial errors notably influence the model's overall performance. Smaller root mean square error (RMSE) values indicate enhanced

model accuracy and a stronger alignment with the observed data. The following formula can calculate the RMSE [31].

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n} (\hat{y}_i - y_i)^2} \qquad (2)$$

### C. Mean Absolute Error (MAE)

Mean Absolute Error (MAE) is an alternate evaluation metric frequently used in regression analysis. It calculates the average absolute discrepancy between forecasted and actual values in a dataset. This discrepancy evaluates the accuracy of forecasts. Unlike Mean Squared Error (MSE), which squares errors before averaging, MAE doesn't square errors [29]. This makes it less influenced by outliers or extreme values. It provides an indication of the average error magnitude in predictions. Smaller MAE values signify improved model performance, similar to MSE. A value of zero denotes perfect correspondence between forecasted and actual values. MAE is particularly helpful where the focus is on absolute error magnitude rather than squared discrepancies. This is because MAE considers absolute error magnitude. Eq. (3), calculates the MAE metric [29].

$$MAE = \frac{1}{n}\sum_{i=1}^{n} |y_i - \hat{y}_i| \qquad (3)$$

### D. R-squared (R2)

R-squared, or coefficient of determination, is a statistical measure assessing the goodness-of-fit of a regression model. It represents the proportion of variance in dependent variables explained by the model's independent variables [30]. The R-squared value ranges from 0 to 1. 1 indicates a perfect fit where the model presents all variability in data. 0 indicates model doesn't show any variability. R-squared can be interpreted as the percentage of variance in dependent variables accounted for by independent variables in the model. Eq. (4) calculates the R-squared [30].

$$R^2 = 1 - \frac{SS_{res}}{SS_{tot}} \qquad (4)$$

## V.    EXPERIMENTAL RESULTS AND DISCUSSION

In this section, we present the experimental results of our study, conducted on a laptop equipped with an 8th generation Intel Core i7 processor, 16GB of RAM, and an NVIDIA GeForce GTX GPU with 8GB. We evaluated the performance of our models using three metrics: Mean Squared Error (MSE), Mean Absolute Error (MAE), and R-squared.

### A. Models Performance Based on All Feature

The RF model has the best performance among these for modelling information diffusion on social media using All Features, as described in Table V. Based on R-squared value, a statistical measure representing a proportion of variance for dependent variables explained by independent variables in the regression model, the RandomForest model appears best performing. It has the highest R-squared value of 0.767, explaining approximately 76.7% of the variance in the dependent variable. Moreover, for MSE and MAE measures of prediction error, the RF model has the lowest scores on the test set. This signifies the smallest prediction errors among models. Therefore, based on provided metrics (R-squared, MSE, and

MAE), the RF model models is provided the best results among used models.

### B. Models Performance Based on Early Retweet Dynamics Features

The ANN model has the best performance for modelling information diffusion on social media using early retweet dynamics features. Based on the R-squared value described in Table VI, the highest R-squared value was achieved by the ANN model, which indicates that it explains approximately 24.30% of the variance in the dependent variable. It is essential to consider that this value is relatively low, which indicates that there is only a limited amount of goodness of fit to the data. Every model could be improved by performing additional tuning or using additional or different features.

TABLE V. RESULTS OF INFORMATION DIFFUSION BASED ON ALL FEATURES

| Model | MSE | RMSE | MAE | R-squared (%) |
|---|---|---|---|---|
| Linear Regression | 46.364 | 6.811 | 5.864 | 33.995 |
| CNN-BiLSTM | 29.610 | 5.440 | 4.482 | 57.846 |
| CNN-GRU | 24.400 | 4.939 | 3.953 | 65.264 |
| ANN | 18.679 | 4.323 | 3.237 | 68.021 |
| RF | 16.374 | 4.048 | 2.599 | 76.690 |

TABLE VI. RESULTS OF INFORMATION DIFFUSION BASED ON EARLY RETWEET DYNAMICS FEATURES

| Model | MSE | RMSE | MAE | R-squared (%) |
|---|---|---|---|---|
| Linear Regression | 53.459 | 7.314 | 5.932 | 8.48 |
| CNN-BiLSTM | 43.708 | 6.609 | 5.740 | 18.32 |
| Random Forest | 46.608 | 6.826 | 5.729 | 20.21 |
| CNN-GRU | 44.626 | 6.678 | 5.810 | 23.60 |
| ANN | 44.212 | 6.645 | 5.776 | 24.309 |

### C. Models Performance Based on Following Network Structure Features

The Random Forest model has the best performance among these for modelling information diffusion on social media using the Following network structure features. Based on R-squared value, Random Forest model is the best performing among these for models, as described in Table VII. It has highest R-squared value of 0.907, explaining approximately 90.7% of the variance in dependent variable. RandomForest model also has lowest MSE and MAE values on the test set, implying smallest prediction errors among models.

### D. Models Performance Based on Retweeting Network Structure

Based on R-squared value, Linear Regression model is best performing among these for modelling information diffusion on social media using retweeting network structure features, as described in Table VIII. It has highest R-squared value of 0.982, explaining approximately 98.2% of the variance in dependent variable.

Although RF model has slightly higher MSE and MAE values on test set compared to Linear Regression, its R-squared value is also very close, making it a strong competitor.

### E. Models Performance Based on Tweet Content Features

The ANN model achieved a higher level of effectiveness in representing the spread of information on social media platforms using tweet content features, as evidenced by the R-squared value. The R-squared of the ANN model is 0.055, suggesting that it explains approximately 5.5% of the variability observed in the dependent variable. Nevertheless, it is crucial to acknowledge that all models exhibit low or negative R-squared values that suggests inadequate alignment with the observed data. Table IX below summarizes the results using Tweet content features.

TABLE VII. RESULTS OF INFORMATION DIFFUSION BASED ON THE FOLLOWING NETWORK STRUCTURE FEATURES

| Model | MSE | RMSE | MAE | R-squared (%) |
|---|---|---|---|---|
| Linear Regression | 46.669 | 6.836 | 5.155 | 20.1 |
| CNN-GRU | 25.957 | 5.095 | 4.086 | 55.6 |
| CNN-BiLSTM | 22.762 | 4.767 | 3.970 | 57.5 |
| ANN | 20.031 | 4.475 | 3.549 | 65.7 |
| RF | 5.389 | 2.322 | 0.999 | 90.8 |

TABLE VIII. THE RESULTS OF INFORMATION DIFFUSION BASED ON RETWEETING NETWORK STRUCTURE

| Model | MSE | RMSE | MAE | R-squared (%) |
|---|---|---|---|---|
| CNN-BiLSTM | 5.846 | 2.416 | 1.392 | 80.1 |
| CNN-GRU | 11.601 | 3.405 | 2.280 | 80.1 |
| ANN | 5.253 | 2.293 | 1.486 | 91.0 |
| Linear Regression | 1.097 | 1.048 | 0.237 | 98.1 |
| Random Forest | 1.074 | 1.036 | 0.233 | 98.2 |

TABLE IX. THE RESULTS OF INFORMATION DIFFUSION BASED ON TWEET CONTENT FEATURES

| Model | MSE | RMSE | MAE | R-squared (%) |
|---|---|---|---|---|
| Linear Regression | 68.593 | 8.289 | 6.708 | -0.174 |
| Random Forest | 68.548 | 8.284 | 6.707 | -0.174 |
| CNN-BiLSTM | 56.095 | 7.491 | 6.289 | 0.040 |
| CNN-GRU | 55.754 | 7.468 | 6.329 | 0.045 |
| ANN | 54.834 | 7.404 | 6.257 | 6.124 |

## V. DISCUSSION

Our findings have significant implications for predicting the spread of information through social media. The models were evaluated based on their ability to capture the intricacies of the information diffusion process. Their performance was measured using various feature sets such as all features, early retweet dynamics, Following network structure, Retweeting network structure and Tweet content. The RF model performance is higher than other models. The model's MSE was 16.374, RMSE was 4.049, MAE was 2.599, and R-squared was 76.690. This result indicates that more accurate predictions of the extent of information dispersion can be achieved by including a wide variety of features. The RF model reduces variation and improves generalization performance by averaging predictions from multiple decision trees.

We also explored how tweet content features play a role in prediction. The ANN model was run on these features, and the results showed that the MSE, RMSE, MAE, and $R^2$ values were as follows: 44.212, 6.645, 5.776, and 24.309, respectively. The model performance was not good when we concentrated most of our attention on early retweet dynamics. Consequently, it would appears that the dynamics of early-stage popularity may not be adequate to accurately predict the extent of information cascades, even though they do play a part in the process of information dissemination.

The impact of network structural features on prediction performance was then examined. The MSE, RMSE, MAE, and R-squared for a RF model trained on the following network architecture were 5.389, 2.321, 0.999, and 90.773, respectively. This shows how the extent of information cascades heavily depends on the level of user influence in the subsequent network. Similar success was seen with a RF model that was trained using variables extracted from the retweeting network; this model achieved an excellent MSE of 1.074, RMSE of 1.036, MAE of 0.233, and an astounding R-squared of 98.161. These findings underline the significance of taking into account the topology of the retweeting network when estimating the rate of information diffusion in a Twitter stream.

Finally, we investigated the significance of tweet content features in the context of prediction. The ANN model, which was exclusively trained using the content of tweets, demonstrated performance metrics including a mean squared error (MSE) of 54.834 , root mean squared error (RMSE) of 7.404, mean absolute error (MAE) of 6.257, and a relatively low R-squared value of 6.124. This implies that the sole consideration of tweet content may not be adequate in accurately predicting the sizes of cascades. Including network structure and the dynamics of early-stage popularity appears essential to understand the intricacies of information diffusion comprehensively.

This study emphasizes the significance of considering various factors in predicting the scale of information diffusion on social media. The optimal predictive performance is achieved by considering a combination of network structure features, early-stage popularity dynamics, and tweet content. The RF models' efficacy in capturing network structure's impact has been demonstrated. In contrast, the ANN model offers valuable insights into the significance of early-stage popularity dynamics.

Subsequent investigations may priorities examining supplementary attributes and integrating more sophisticated machine learning and deep learning methodologies to enhance the precision of predicting information dissemination on social media platforms. Fig. 5 shows the regression plots for the best models performance for information diffusion.
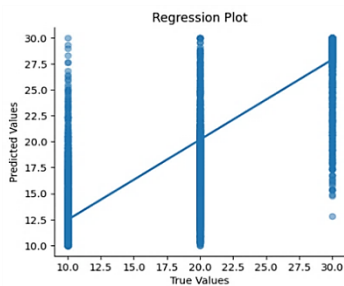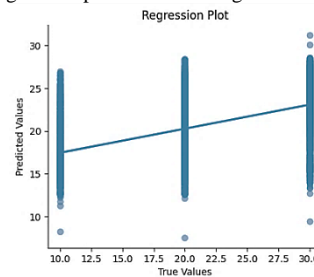


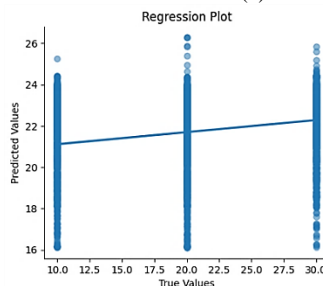(a) The RF regression performance using all features.
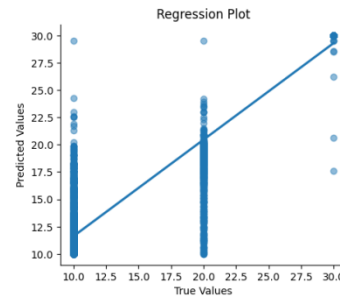


(b) The RF regression performance using following network structure features.
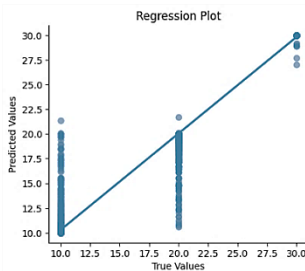


(c) The RF regression performance using Retweeting network structure.



(d) The ANN regression performance using Early retweet dynamics.



(e) The ANN regression performance using Tweet content features.

Fig. 5.   Shows the combination of various regression models performance plots for predicting information diffusion.

Table X summaries the best results obtained from our experimental work carried out in this study.

TABLE X.   PRESENTING THE BEST RESULTS OF OVERALL

| Features Used | Best Model | MSE | RMSE | MAE | R-squared (%) |
|---|---|---|---|---|---|
| All features | Random Forest | 16.374 | 4.049 | 2.599 | 76.690 |
| Early retweet dynamics | ANN | 44.212 | 6.645 | 5.776 | 24.309 |
| Following network structure | Random Forest | 5.389 | 2.321 | 0.999 | 90.8 |
| Retweeting network structure | Random Forest | 1.074 | 1.036 | 0.233 | 98.2 |
| Tweet content | ANN | 54.834 | 7.404 | 6.257 | 6.124 |

As shown in above cited X table, the best results gained for information diffusion on social media by the ANN and RF models. The results emphases on important findings  with various characteristics that perform differently in terms of models, and some features have better predictive ability and accuracy when it comes to comprehending the dynamics of information dissemination on social media platforms. The R-squared values provide information about how well the models represent the diffusion process's variability. These results advance our knowledge of information distribution inside social media networks in a more complex way.

Fig. 6 presents the visualization of the best results for the proposed models.
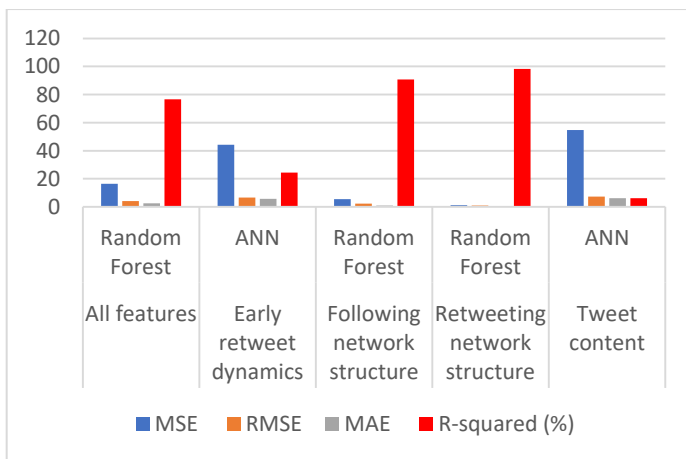


Fig. 6.   Graphical representation shows the best models performance and results.

In our research study, we compared how well our models predicts the spread of information based on retweets and retweet counts versus another study that used XGBoost modeling. We aim methodically to evaluate our model's performance with exist ones. We observed the root mean squared error (RMSE) - a standard way of measuring how closely regression models predict values. We investigated the RMSE for different features, like, all features, early retweet dynamics, Following network, Retweeting network, Tweet content. Authors in study [7]  used XGBoost model, which had RMSE ranging from 134 to 237 for the different features. Our models using RF and neural networks performed much better,

with RMSE from 1.036 to 7.404 as described in Table XI. These results demonstrate our models predict information diffusion from retweets and retweet counts far more accurately than the XGBoost models in the other study. Our models matched the real dynamics of information spreading much closer, as shown by the lower RMSE values.

TABLE XI.   A COMPARISON BETWEEN THE RESULTS OF OUR APPROACH WITH EXISTING ONES

| Features | Result from Study [7] (XGBoost ) | Our  Study (RF / ANN) |
|---|---|---|
| All features | 196 | 4.049 |
| Early retweet dynamics | 237 | 6.645 |
| Following network | 151 | 2.321 |
| Retweeting network | 134 | 1.036 |
| Tweet content | 205 | 7.404 |

## VI.   CONCLUSION

This study predicted social media information diffusion based on the number of retweets and retweets counts. The deep learning and machine learning models were trained on Weibo, a social network platform similar to Twitter. Those models used various features such as all features, early retweet dynamics, following network structure, Retweeting network structure, and Tweet content. The best result was achieved by RF 98.161 using Retweeting network structure features. The results of our study provide insights into mechanisms of information dissemination on social media platforms and provide guidance for predicting potential influence of forthcoming news events. Optimal predictive performance is attained by considering interplay of network structure, early popularity dynamics, and features inherent to tweet content .Accurate information diffusion prediction helps businesses improve their marketing strategies, public health officials respond to disease outbreaks, and identify social network influencers. The present study has potential to establish a fundamental basis for future investigations integrating cutting-edge machine learning and deep learning techniques to explore supplementary variables and other social media features that can enhance precision of predictions of information diffusion on online platforms. Enhancements in capacity to forecast extent of information dissemination hold significant potential for various domains, including advertising, crisis management, and examination of online social dynamics.

## REFERENCES

[1] Nam, Y. W., Son, I. S., & Lee, D. W. "The impact of message characteristics on online viral diffusion in online social media services: The case of Twitter". Journal of Intelligence and Information Systems, 17(4), 2011, pp. 75-94.

[2] Kumar, N. "Information Diffusion and Summarization in Social Networks" (Doctoral dissertation, IIT Hyderabad, India), 2019, pp. 2019.

[3] Hatua, A., Nguyen, T. T., & Sung, A. H. "Information diffusion on Twitter: Pattern recognition and prediction of volume, sentiment, and influence". In Proceedings of the 4th IEEE/ACM International Conference on Big Data Computing, Applications and Technologies (BDCAT), 2017, pp. 157-167. doi: 10.1145/3148055.3148078.

[4] Al-Taie, M. Z., & Kadry, S. "Information Diffusion in Social Networks". In Python for Graph and Network Analysis, 2017, pp. 165. doi: 10.1007/978-3-319-53004-8_8.

[5] Masud, S., et al. "Hate is the New Infodemic: A Topic-aware Modeling of Hate Speech Diffusion on Twitter". Proceedings of the International Conference on Data Engineering (ICDE), 2020, pp. 504-515. doi: 10.1109/ICDE51399.2021.00050.

[6] Kushwaha, A. K., Kar, A. K., & Ilavarasan, P. V. "Predicting Information Diffusion on Twitter: A Deep Learning Neural Network Model Using Custom Weighted Word Features". Lecture Notes in Computer Science (LNCS), 2020, pp. 456-468. doi: 10.1007/978-3-030-44999-5_38.

[7] Cao, R. M., Liu, X. F., & Xu, X. K. "Why cannot long-term cascade be predicted? Exploring temporal dynamics in information diffusion processes". R Soc Open Sci, 8(9), 2021, pp. 2021. doi: 10.1098/RSOS.202245.

[8] Razaque, A., Rizvi, S., Khan, M. J., Almiani, M., & Al Rahayfeh, A. "State-of-art review of information diffusion models and their impact on social network vulnerabilities". Journal of King Saud University - Computer and Information Sciences, 34(1), 2022, pp. 1275-1294. doi: 10.1016/J.JKSUCI.2019.08.008.

[9] Vargo, C. J. "Brand messages on Twitter: Predicting diffusion with textual characteristics", (Doctoral dissertation, The University of North Carolina at Chapel Hill), 2014, pp. 2014.

[10] Lytvyniuk, K., Sharma, R., & Jurek-Loughrey, A. "Predicting Information Diffusion in Online Social Platforms: A Twitter Case Study". Studies in Computational Intelligence, 812, 2018, pp. 405-417. doi: 10.1007/978-3-030-05411-3.

[11] Kafeza, E., Kanavos, A., Makris, C., & Vikatos, P. "Predicting information diffusion patterns in twitter". IFIP Adv Inf Commun Technol, 436, 2014, pp. 79-89. doi: 10.1007/978-3-662-44654-6_8/COVER.

[12] Wang, L., Niu, J., & Yu, S. "SentiDiff: Combining Textual Information and Sentiment Diffusion Patterns for Twitter Sentiment Analysis". IEEE Trans Knowl Data Eng, 32(10), 2020, pp. 2026-2039. doi: 10.1109/TKDE.2019.2913641.

[13] Wang, J., Zheng, V. W., Liu, Z., & Chang, K. C. C. "Topological Recurrent Neural Network for Diffusion Prediction". Proceedings of the IEEE International Conference on Data Mining (ICDM), 2017, pp. 475-484. doi: 10.1109/ICDM.2017.57.

[14] Sankar, A., Zhang, X., Krishnan, A., & Han, J. "Inf-VAE: A Variational Autoencoder Framework to Integrate Homophily and Influence in Diffusion Prediction". doi: 10.1145/3336191.

[15] Zhang, Z., Zhao, W., Yang, J., Paris, C., & Nepal, S. "Learning influence probabilities and modelling influence diffusion in Twitter". The Web Conference 2019 - Companion of the World Wide Web Conference (WWW), 2019, pp. 1087-1094. doi: 10.1145/3308560.3316701.

[16] Kushwaha, A. K., Kar, A. K., & Ilavarasan, P. V. "Predicting Information Diffusion on Twitter: A Deep Learning Neural Network Model Using Custom Weighted Word Features". 2020, pp. 2020. doi: 10.1007/978-3-030-44999-5_38.

[17] Bich, T., Hoang, N., & Mothe, J. "Predicting information diffusion on Twitter – Analysis of predictive features". J Comput Sci, 2017, pp. 2017. doi: 10.1016/j.jocs.2017.10.010.

[18] Suh, B., Hong, L., Pirolli, P., & Chi, E. H. "Want to be retweeted? Large scale analytics on factors impacting retweet in twitter network". Proceedings - SocialCom 2010: 2nd IEEE International Conference on Social Computing, PASSAT 2010: 2nd IEEE International Conference on Privacy, Security, Risk and Trust, 2010, pp. 177-184. doi: 10.1109/SOCIALCOM.2010.33.

[19] Petrovic, S., Osborne, M., & Lavrenko, V. "RT to Win! Predicting Message Propagation in Twitter". Proceedings of the International AAAI Conference on Web and Social Media, 5(1), 2011, pp. 586-589. doi: 10.1609/ICWSM.V5I1.14149.

[20] Kupavskii, A., Ostroumova, L., Umnov, A., Usachev, S., Serdyukov, P., Gusev, G., & Kustarev, A. "Prediction of retweet cascade size over time". In Proceedings of the 21st ACM International Conference on Information and Knowledge Management (CIKM), 2012, pp. 2335-2338.

[21] Quackenbush, J. "Microarray data normalization and transformation". Nature genetics, 32(4), 2002, pp. 496-501. doi: 10.1038/NG1032.

[22] Bro, R., & Smilde, A. K. "Principal component analysis". Analytical Methods, 6(9), 2014, pp. 2812-2831. doi: 10.1039/C3AY41907J.

[23] Mahesh, B. "Machine learning algorithms-a review". International Journal of Science and Research (IJSR), 9(1), 2020, pp. 381-386.

[24] Aalen, O. O. "A linear regression model for the analysis of life times". Stat Med, 8(8), 1989, pp. 907-925. doi: 10.1002/SIM.4780080803.

[25] Grömping, U. "Variable Importance Assessment in Regression: Linear Regression versus Random Forest". Vol. 63, no. 4, 2012, pp. 308-319. doi: 10.1198/TAST.2009.08199.

[26] Rhanoui, M., Mikram, M., Yousfi, S., & Barzali, S. "A CNN-BiLSTM Model for Document-Level Sentiment Analysis". Machine Learning and Knowledge Extraction 2019, 1(3), 2019, pp. 832-847. doi: 10.3390/MAKE1030048.

[27] Jain, A. K., Mao, J., & Mohiuddin, K. M. "Artificial neural networks: A tutorial". Computer (Long Beach Calif), 29(3), 1996, pp. 31-44. doi: 10.1109/2.485891.

[28] Das, K., Jiang, J., & Rao, J. N. K. "Mean squared error of empirical predictor". Vol. 32, no. 2, 2004, pp. 818-840. doi: 10.1214/009053604000000201.

[29] Chai, T., & Draxler, R. R. "Root mean square error (RMSE) or mean absolute error (MAE)? – Arguments against avoiding RMSE in the literature". Geoscientific model development, 7(3), 2014, pp. 1247-1250.

[30] Cameron, A. C., & Windmeijer, F. A. G. "R-Squared Measures for Count Data Regression Models With Applications to Health-Care Utilization". Vol. 14, no. 2, 2012, pp.209-220.doi: 10.1080/07350015.1996.10524648.

[31] Willmott, C. J., & Matsuura, K. "Advantages of the mean absolute error (MAE) over the root mean square error (RMSE) in assessing average model performance". Clim Res, 30(1), 2005, pp. 79-82. doi: 10.3354/CR030079.

[32] Ma, C., Yan, Z., & Chen, C. W. "LARM: A Lifetime Aware Regression Model for Predicting YouTube Video Popularity". Proceedings of the 2017 ACM on Conference on Information and Knowledge Management (CIKM), 2017, pp. 467-476.

[33] Hong, L., Dan, O., & Davison, B. D. "Predicting popular messages in Twitter". Proceedings of the 20th Int. Conf. Companion on World Wide Web - WWW '11, New York, NY: ACM Press, 2011. doi: 10.1145/1963192.1963222.

[34] Yan, Z., Zhou, X., Ren, J., Zhang, Q., & Du, R. (2023). Identifying underlying influential factors in information diffusion process on social media platform: A hybrid approach of data mining and time series regression. Information Processing & Management, 60(5), 103438.